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ENHANCING TRICKLING FILTER PLANT PERFORMANCE BY CHEMICAL PRECIPITATION

Robert E. Derrington, et al

Richardson, Texas

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ENHANCING TRICKLING FILTER PLANT PERFORMANCE BY CHEMICAL PRECIPITATION

by

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For the: City of Richardson, Texas
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Grant No. S800685
Project 11010 EGL

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ABSTRACT

Two years of plant-scale studies indicated metal addition was an effective effluent polishing technique at this conventional wastewater treatment plant. Effluent phosphorus (P), five-day BOD_5 and suspended solids were reduced to 0.5, 5, and 7 mg/l respectively. Aluminum sulfate was more effective than ferric chloride. Alum addition ahead of the final clarifier proved the best arrangement. An optimum mole ratio (metal/phosphorus) of 1.6 developed; this ratio shows moles of aluminum fed per mole of incoming total phosphorus. Chemical costs, of which one-third was for transportation, were 5 cents per 1,000 gallons of flow treated, or 36 cents per pound of phosphorus removed when in the 96 percent removal range. Chemical addition doubled the volume of digested sludge but dewatering on sand beds took half as long as previous conventional operations. During this demonstration the treatment system received some 1.6 MGD of typical domestic discharge, essentially its design loading. Hydraulic loading on clarifiers was minimized by drastic reduction of recirculation flows.

This report was submitted by the City of Richardson, Texas (P. O. Box 309, Zip Code 75080) in fulfillment of Grant Number 11010 EGL, Project Number S800685 under the partial sponsorship of the U. S. Environmental Protection Agency.

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SECTION I

CONCLUSIONS

Based on two years of mineral addition to the 1.6 MGD City of Richardson, Texas, single-stage standard-rate trickling filter plant:

1. Characteristics of the wastewater were typical of domestic sewage.

2. The plant was operating at near design load during the project. Hydraulic loadings on clarifiers were kept low by reducing recirculation to a minimum. Daily peak flows were minimized by control of main pumps.

3. Addition of liquid alum ahead of the final clarifier was the easiest and most effective means of chemical addition. Mole ratios (Al/P) of 1.6/1.0 yielded consistent effluent concentrations (mg/l) of 0.5 for phosphorus, 5 for BOD_5 and 7 for suspended solids. This level of treatment represents a significant upgrading of overall performance compared to the capabilities of the plant when operated in a conventional mode without chemical addition.

4. Chemical costs were 5 cents per thousand gallons flow, or 36 cents per pound of phosphorus removed, with phosphorus removal at the 96 percent level.

5. Higher aluminum dosages, as much as 50 percent more than cited in 3 above, produced only slightly better results.

6. Addition of liquid alum ahead of the primary clarifiers was not as effective an approach as alum addition to the final clarifier and caused solids handling problems in the digesters. Split feed (simultaneously to primary and final clarifiers) was an effective approach but was not worth the extra effort required.

7. Liquid ferric chloride addition did not work as well as alum addition. Discrete iron colloids escaped the treatment system under all iron addition approaches tried. Effluent quality did not match alum treatment even at iron/phosphorus mole ratios of 2/1.

8. Polymers aided in the capture of discrete colloids but were not needed when alum addition was performed properly.

9. To prevent phosphorus breakthrough, the rate of metal addition had to be matched with the incoming phosphorus load. This required changing pump settings four times per day.

10. Separate supernatant treatment was necessary for optimum plant performances. A single continuous alum treatment system reduced pollutants in supernatant to levels below those found in raw wastewater.

11. Residual pollutant levels in alum clarified trickling filter effluent were reduced by 50 percent or more after passage through a tertiary pilot-scale high-rate multimedia filter unit. When pilot carbon columns were added to the tertiary sequence, pollutants were reduced to near trace levels.

12. Chemical treatment doubled the volume of anaerobically digested sludge to be handled; however, the digested sludge could be dried on and removed from sand beds in half the usual time.

SECTION II

RECOMMENDATIONS

The personnel involved in this project have pooled their observations and experiences to offer suggestions to others considering similar operations.

To those who wish, outside of chemical addition, to improve overall plant performance:

1. Treat supernatant from anaerobic digesters before returning it to the plant inflow. Such treatment can involve a simple continuous system which yields a very treatable return liquor. Cost should be less than one quarter cent per thousand gallons of plant flow.

2. When sand beds are "stripped" of dry sludge, take time to maintain them. Fluff or scarify the surface of the beds and let the sand dry. Add coarse sand as required to offset attrition. These simple measures can cut drying time by one-third and produce bed underflow of secondary effluent quality.

3. Require operators to become members of the laboratory team. Encourage them to observe gross features such as turbidity, color, and smell. Also, have them make in situ tests for temperature, pH, dissolved oxygen and settable solids. More to the point, teach operators to respond to changes in these parameters rather than report them for historical record only.

To those who wish to enhance effluent quality by chemical addition at a standard-rate trickling filter plant:

1. Provide continuous around-the-clock operation at the plant.

2. Equalize flow through the plant by every available means until it is as near constant as possible. This does not infer recirculation is equalization; the aim is to equalize untreated inflow.

3. Reduce hydraulic loading on final clarifiers to a minimum. Five hundred gallons per day per square foot (based on surface overflow) is a realistic and important goal.

4. Reduce debilitating effects of strong local currents in all clarifiers by providing velocity dissipation of inflow. Use chemical floc as a tracer to indicate inflow baffling needs and progress.

5. Take all possible means to increase low energy flocculation and settling times in clarifiers. This infers increasing clarifier design depth in new plants, and possible addition of skirts or baffles in the feed wells of existing units.

6. Monitor and characterize incoming phosphorus levels. Adjust chemical feed rate to match changes in the rate of incoming phosphorus. Monitor the effluent to evaluate phosphorus removal effectiveness.

7. Pipe chemical feed facilities to provide several possible feed points. Try all of these, and combinations of several, to determine the best chemical dosing regimen for a particular plant.

8. Insure flash mix operations are truly high energy complete dispersion operations. G-values should exceed 500 for metal dispersal, but should be reduced to 25 to 100 for polymer mixing.

9. Do not draw digested sludge too deeply into drying beds (10 or 11 inches is typical maximum) or chemical sludge will compress, blind the bed off, and result in long drying times.

10. In judging the effectiveness of chemical addition, consider changes in suspended solids, turbidity, biochemical or chemical oxygen demand, total organic carbon, and coliforms as well as phosphorus.

SECTION III

INTRODUCTION

The overriding purpose of this study was to demonstrate that controlled in-plant chemical addition could substantially upgrade overall performance of a full-scale standard-rate trickling filter plant. One major objective was operation of the plant to reduce phosphorus concentration (as P) to a level of one mg/l or less. Other goals included reduction of BOD_5 and suspended solids to concentrations of 15 mg/l or less. It was felt that improving treatment in a conventional plant to these levels, consistently and economically, would serve as a valuable test case and could thus make a contribution towards enhancing performance of thousands of other trickling filter plants in use today.

Facilities for this plant-scale study were provided, to the greatest extent possible, through modification of existing treatment units. Existing facilities were adapted to new roles rather than installing major new units alongside them. The scope of this report includes a description of modifications undertaken, a description of chemical feed equipment and dosing options, a summary of pertinent results, and discussion of those results.

The only tertiary treatment evaluation undertaken in this project involved pilot-scale units for multi-media filtration and carbon absorption. Operation of these pilot-plant units was considered a secondary study, and is presented in that perspective in this report.

PROJECT DEVELOPMENT AND SCHEDULE

In the middle 1960's, operators of the Richardson, Texas treatment plant began to add chemicals, of several types and in various ways, in attempts to improve plant performance. Initial results were encouraging and, in 1966, a letter was written to the precursor of the United States Environmental Protection Agency inquiring whether there was merit in an expanded plant-scale investigation. A favorable response from the Agency led to further developments and an application for support of the present study was submitted in April, 1969. A research and development grant was awarded to the City in June, 1969.

It took a full year to complete detailed plans, order and receive equipment, and complete all phases of plant construction. However, it was possible to make operational baseline studies during the latter portion of that first year (Figure 1).

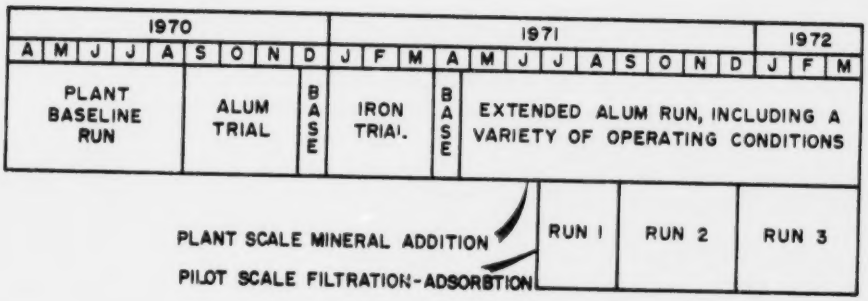

FIGURE 1. TWENTY-FOUR MONTH SCHEDULE OF DATA ACCUMULATION.

Trial operations with liquid alum were carried out during the last quarter of 1970. A trial with ferric chloride was made during the first quarter of 1971. Finally, after alum was selected as the more promising chemical additive, an extended alum run was made during the next eleven months through March, 1972.

FUNDAMENTALS OF METAL SALT ADDITION

These introductory comments are not intended to detail an extensive literature search nor do they offer an extended theoretical consideration of the chemistry involved. Instead, several fundamentals dictated the physical arrangement and mode of operation and, in retrospect, seem to be important insights into assembling a chemical addition system for a conventional secondary treatment plant. Those fundamentals are discussed below.

Chemical addition has two major overall functions: (1) precipitation of phosphorus and (2) removal of the greatest possible amount of colloids. It was assumed that phosphorus precipitation was brought about solely by metal salts. Conversely, coagulation or destabilization of colloids was considered a function of both metals and polymers. Finally, flocculation of destabilized colloids was also presumed a function of both metals and polymers.

The first function mentioned, precipitation of phosphorus, involves some obscure reactions. Recht and Ghassemi (1) have undertaken explorations into this field and offer numerous references to other investigations. Reaction products appear to be a variety of metal phosphates and

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17a. Descriptors * Biological Treatment, * Chemical Precipitation, * Oxygen Demand, * Phosphorus, * Suspended Solids, * Tertiary Treatment, * Trickling Filters, * Wastewater Treatment, Activated Carbon, Biochemical Oxygen Demand, Chemical Oxygen Demand, Coagulation, Colloids, Data Processing, Dispersion, Diurnal Distribution, Domestic Wastes, Feeding Rates, * Filtration, Flocculation, Laboratory Tests, Nutrient Removal, Sedimentation, Sewage Treatment, Sludge Disposal, * Texas, Tracers, Treatment Facilities.

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* Richardson (Texas)

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related species, according to a study committee of the American Water Works Association (2) and Theis, et al (3). An important factor in kinetics has been demonstrated: the precipitation reaction is essentially complete in less than one second. Addition of acid metal salts will depress pH, but this would rarely interfere with phosphorus precipitation. Since polymers are not involved in this reaction, their addition should be deferred until this phase is completed.

The second function, coagulation of all types of colloids in the water phase, has received more intensive study over recent years. Again, the American Water Works Association has recently published an extensive committee report on this subject (4). It is now widely accepted that metal coagulation is a very rapid reaction, taking place in less than one second. The resulting metal colloids appear to be extremely complicated and probably involve a series of related polymers as described by Bilinski and Tyree (5). Polymers also induce coagulation but their reaction rates are on the order of seconds to minutes in duration. The very process of biological treatment of wastewater apparently creates a separate variety of natural polymers; their role is obscure at present according to Dean (6) and Busch and Stumm (7). In any event, the function of coagulation in this project was considered to be destabilization of discrete colloids so that they might be flocculated and separated from the wastewater.

The final function of the chemicals added was promotion of flocculation or progressive agglomeration of the colloids into solids which could be physically separated and handled. Flocculation is certainly the most visible and probably the best understood of the reactions mentioned here. The process of flocculation was visualized and physically provided for via the same general approach used in present water treatment technology.

When taken together, the fundamentals reviewed here fairly well dictated the physical facilities which would be required. For each point of chemical addition, flash mixing of metal salts was provided for a period of a few seconds. Following that, high energy flocculation was established for a period of one to five minutes followed finally by low energy flocculation for approximately five to twenty minutes. Polymers were added at a point some two minutes into the high energy flocculation phase. In all cases, the facility requirements were modest and were largely inherent in the existing treatment units.

More specifically, the only precalculated addition of chemical reaction (precipitation, coagulation, or flocculation) equipment was for the purpose of flash mixing. Available hydraulic conditions were used to promote a reasonable degree of flocculation. Although this was the least expensive approach, it also entailed the greatest risk of operational difficulty. However, this approach may very well be the one that would most likely be taken at other plants.

Finally, the operators involved in this project were those who, except for normal personnel turnover, worked at the plant both before and since

the time of the study. In terms of experience (5 year average) and training they probably are near the norm for the operating profession. The question of whether they could meet the challenge of understanding chemical precipitation and applying this understanding to control of the equipment was a very real part of the effort reported here.

SECTION IV

DESCRIPTION OF TREATMENT FACILITIES

Treatment facilities at the City of Richardson, Texas consist of a conventional secondary system designed to handle domestic wastewater. The first phase was built in 1953; the addition of a parallel unit in 1961 extended plant capacity to 1.6 MGD. Modifications for chemical addition in 1969 were minor and did not materially alter the basic facilities or flow pattern. Tertiary pilot plant units were added beside the final clarifier in 1971.

FACILITIES PRIOR TO PROJECT

The plant is a typical standard-rate single-stage trickling filter system. Plant facilities are shown in Figure 2.

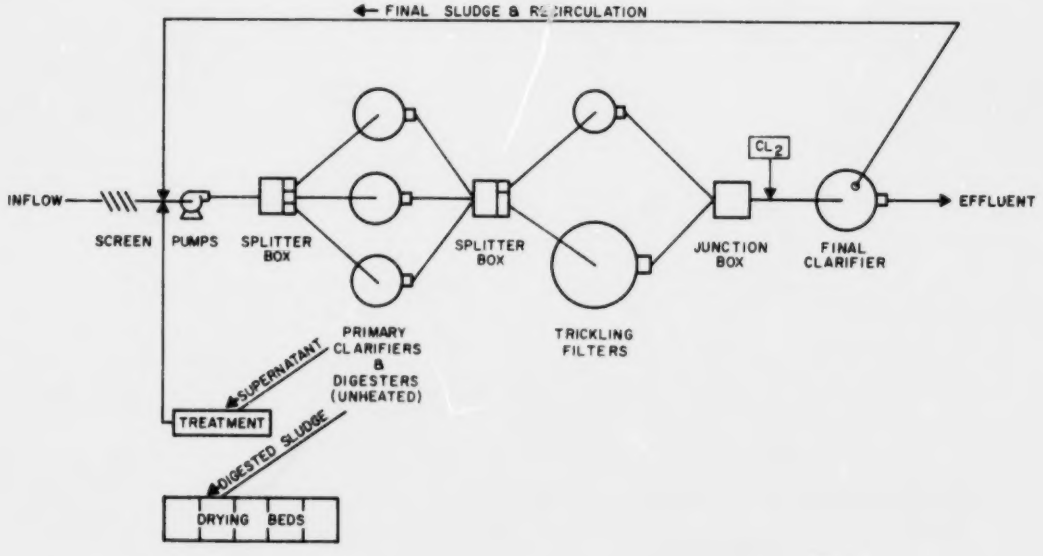

FIGURE 2. TREATMENT PLANT PRIOR TO MODIFICATION.

A mechanical bar screen precedes a wet well serving four raw sewage pumps which lift the wastewater into a flow splitter box. Proportional weirs there divide flow between three clarifier-digesters. Primary effluent is combined in a splitter box, then divided and sent to two standard-rate rock filters. Filter effluent is combined and carried to the final clarifier. Chlorination and settling occur at the same time in that clarifier. A mixture of settled trickling filter humus and recirculated effluent are drawn from the bottom of the final clarifier and returned to the head of the plant, the amount of recirculation usually being regulated by a level control system in the raw sewage wet well.

Sludge is digested in the lower compartment of each primary clarifier-digester. No heat is provided (gas is wasted through a burner) and mixing consists of gentle stirring by a 3 rph mechanism revolving on the same shaft as the clarifier rakes above.

Digested sludge is dried on sand beds. Filtrate collected in the underdrains flows back to the head of the plant. Prior to the grant project, digester supernatant was drawn and batch-treated before return to the head of the plant as shown in Figure 3.

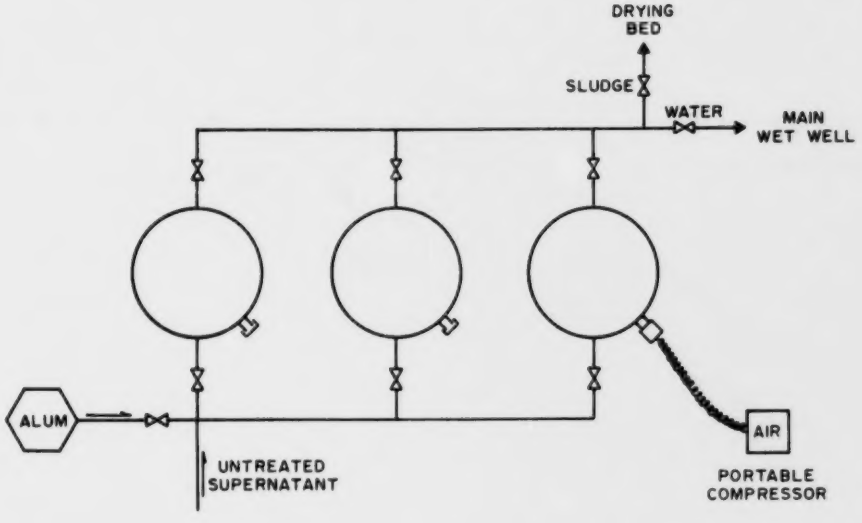

FIGURE 3. ORIGINAL BATCH-TYPE SUPERNATANT TREATMENT SYSTEM. (Equipment was modified during project as shown in Figure 6.)

Three 500-gallon fill-and-draw tanks received raw supernatant. Approximately 250 mg/l of alum was added followed by 20 minutes of air agitation to yield a finished liquor which separated into sludge (which went to drying beds) and treated supernatant with strength comparable to raw sewage.

Detailed plant data are condensed into Table 1.

TABLE 1

DATA ON TREATMENT UNITS

	Diam (Ft)	Depth (Ft)	Area (Sq Ft)	Volume (Cu Ft)	(Gal)
Prim. Clar. No. 1	40	8	1257	10,054	75,200
2	40	10	1257	12,570	94,000
3	40	10	1257	12,570	94,000
All Prim. Clar.	--	--	3771	35,194	263,200
Final Clarifier	70	6	3848	23,088	173,000
Filter No. 1	84	6.5	5542(1)	36,000	---
2	120	6.5	11310(1)	73,500	---
Filters Combined	---	---	16852(1)	109,500	---
Digester No. 1	40	14.3(2)	1257	13,000	97,000
2	40	14.3(2)	1257	13,000	97,000
3	40	14.3(2)	1257	13,000	97,000
Digesters Combined	--	---	---	39,000	291,000

Sludge Drying Beds 12,000 Square Feet

(1) Area in acres: 0.127, 0.260 and 0.387, respectively
(2) 14.3 Effective, 18.0 SWD, 15.8 Clear @ Center

Before the present study began, existing facilities were brought to their best mechanical efficiency. All three digesters were drained and cleaned. Flow meters were recalibrated.

MODIFICATIONS TO TREATMENT UNITS

In this project, chemical treatment was intended as an adjunct to the physical and biological treatment already provided. Further, it was

intended that required modifications be as simple as possible and that existing facilities be fully utilized.

Early in the project two coagulants were selected for operational trials: (1) aluminum in the form of liquid alum and (2) iron as liquid ferric chloride. Both were available in bulk from commercial firms at haul distances of about 250 miles. Both were similar enough in character to permit use of common storage and feeding hardware. Use of polymers was also projected based on the assumption they would be worthwhile in improving settling characteristics of solids involved.

At this point the arrangement of the plant was modified to permit addition of these chemicals in the main wet well and just ahead of the final clarifier as indicated in Figure 4.

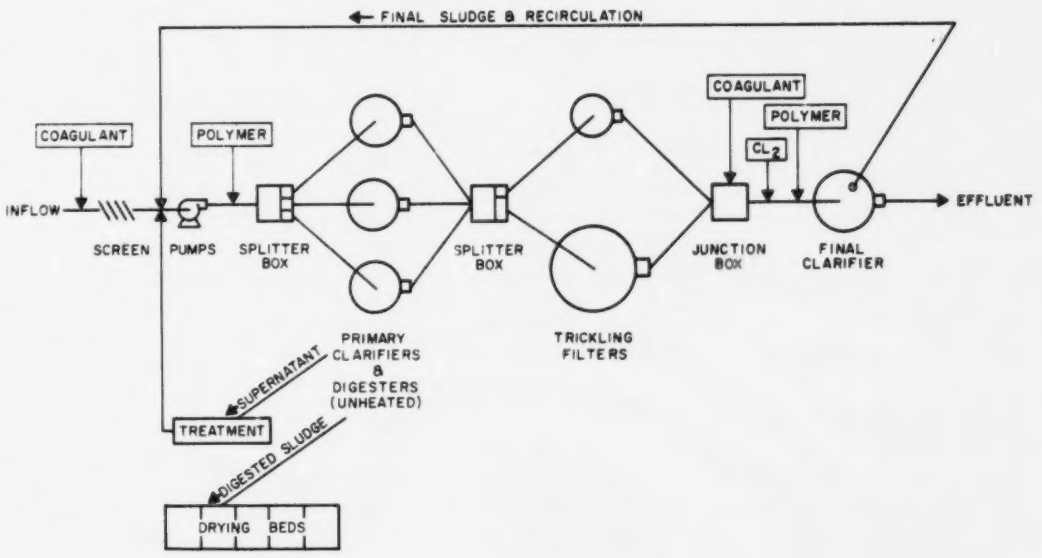

FIGURE 4. PLANT MODIFIED FOR CHEMICAL ADDITION.

One 6000-gallon fiberglass tank was installed for storing liquid coagulant in a central location. This capacity was sufficient to receive tanktruck lots of any chemical considered. Two chemical feed pumps were installed beside the tank and piped to deliver to either the head

or effluent ends of the plant, or both simultaneously. Both pumps included variable feed controls covering their 0-110 gph discharge range. Pump controls also were equipped with automatic-manual capability. Wetted parts were selected of materials resistent to alum, ferric chloride, sodium aluminate, and pickle liquor.

Two 1200-gallon fiberglass polymer storage tanks were provided, one near the plant influent sewer and the other near the final clarifier. Both had feed pumps similar to the pair at the coagulant tank. Both polymer stock tanks were fitted with eductor assemblies for dissolving polymer, and 3-hp mixers for blending fresh batches of polyelectrolytes.

The junction box preceding the final clarifier was modified to provide flash mixing of coagulant. The change involved baffling off a section and installing a 3-hp mixer to promote rapid dispersal of the metal salts injected. The arrangement is shown in Figure 5.

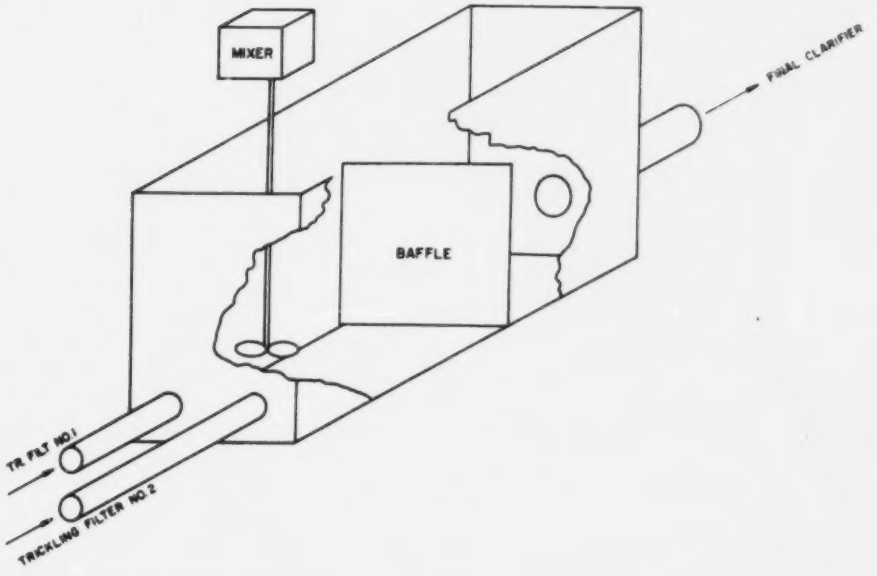

FIGURE 5. CONVERSION OF JUNCTION BOX TO FLASH MIX UNIT. (Physical changes were simple, but carefully planned.)

The mixer delivered a measured 2.2 water hp, making the approximate velocity gradient, or G-value, equal to 650/second. At the average flow of 1.6 MGD, detention was some 50 seconds, so Gt equaled 32,000.

Water confined in front of the baffle was considered in the mixing zone. After flowing over the baffle, water in transit through the remainder of the junction box, through the clarifier inlet pipe, or in the clarifier centerwell was considered in a high energy flocculation zone. Observation of floc-laden water just outside the centerwell allowed an estimate of volume undergoing low energy flocculation. Volumes involved were:

Flash Mix	1,000 gal
High Energy Flocculation	4,000
Low Energy Flocculation	20,000
TOTAL VOLUME	25,000 gal

Table 2 shows nominal detention times in the above zones under different rates of flow.

TABLE 2

DURATION OF FLASH MIX AND FLOCCULATION

Flow Rate		Coagulation	Flocculation Time (Minutes)		
MGD	GPM	(Minutes)	High Energy	Low Energy	Total
1	700	1.42	5.71	28.6	34.3
1.5	1,050	0.95	3.81	19.1	22.9
2	1,400	0.71	2.86	14.3	17.2
2.5	1,750	0.57	2.28	11.4	13.7
3	2,100	0.48	1.91	9.5	11.4

Kinetic energy of turbulent flow entering the wet well was used for flash mixing coagulants added to raw sewage. Chemicals were injected at a manhole to initiate the mixing process in a ten-foot length of steeply descending sewer carrying plant inflow to the wet well. Dispersal was completed in a confined receiving zone in the wet well.

After a brief (and indeterminant) stay in the wet well, incoming flow was pumped into the splitter box preceding the primary clarifiers. Detention time was short and energy levels were fairly high from pumps to

primary clarifiers. This was followed by flocculation in the centerwell area of the clarifiers. An estimate of the size of the flocculation zones in this section of the plant was not possible.

In summary, coagulant dispersal and flocculation in raw sewage took place at ill-defined energy levels and reaction periods. The arrangement was probably not as effective as that provided after the trickling filters.

At both injection points in the plant, polymer injection facilities delivered into high energy flocculation zones. Polymer stock solution water was metered, then mixed with 20 gpm carriage water and jetted into a hydraulic regime where there was sufficient turbulence to promote dispersal. A two-minute lag time was intended between injection of coagulant and addition of polymers.

In 1971, continuous supernatant treatment evolved from the original batch system. As shown in Figure 6, one of the three 500-gallon tanks was piped to serve as a flow-through chemical addition chamber with air agitation. The remaining two tanks were rigged to serve as settling vessels, working in series as shown, or parallel. With inflow diverted upwards at midpoint, both settling tanks offered half their 500-gallon volume to the 30 gpm flow, yielding some eight minutes detention in each tank. This arrangement reduced required operator attendance and produced a high quality treated supernatant.

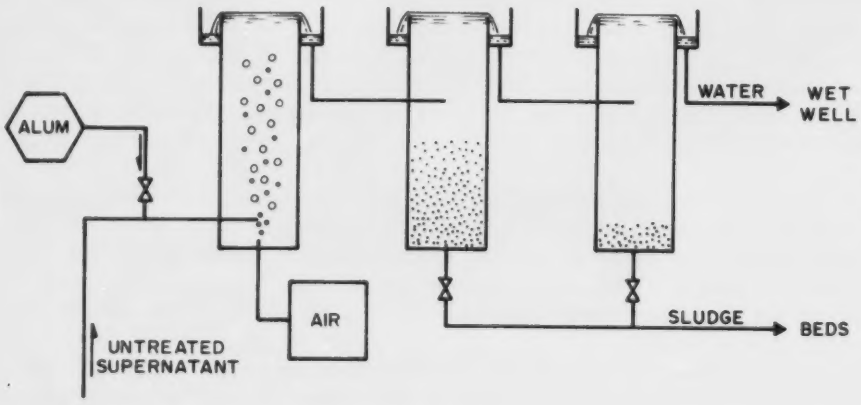

FIGURE 6. IMPROVED CONTINUOUS SUPERNATANT TREATMENT SYSTEM. (Total of 30 minutes of treatment included chemical treatment plus two-stage settling. Operation became largely unattended.)

IMPROVEMENTS IN FLOW CONTROL AND SAMPLING

One primary clarifier was found to suffer poor inlet hydraulics due to the piping arrangement into its centerwell skirt. A combination splitter-deflector was fabricated and installed to redirect inflow and served to effectively dissipate velocity in the centerwell.

There were some inaccuracies in control of flow in the splitter box preceding the trickling filters. Previously, this had been regulated by manual adjustment of sluice gates. Proportional weirs were fabricated and installed in the box, insuring an accurate division to the two different size filters at all rates of flow.

Recirculation flow (which included settled trickling filter sludge) had not been sampled and analyzed previously. The flow was drawn from the bottom of the final clarifier through a gravity line to the raw sewage wet well. A vault housed a flow meter and an air-operated throttling valve at the midpoint of the line. Facilities for automatic sampling were installed in that vault to function as shown in Figure 7.

A continuous sample flow was withdrawn and split between a constant head shunt and a sample shunt which normally diverted to drain. When the flow meter generated a signal indicating flow in the recirculation line, that same signal energized a solenoid diverting sample flow to a receiving can. The amount of sample caught was proportional to the amount of recirculation flow.

The throttling valve on the plant recirculation line had, for years, been controlled by water level in the wet well. Recirculation occurred on a demand basis, making up the deficit between the selected pumping rate and plant inflow. For reasons discussed later it became necessary to sharply reduce this flow. An electric timer was wired into the valve control circuit in a manner which allowed it to override other signals. This timer was eventually set to trigger a 25-second flushing flow every 20 minutes; this pattern established a 70,000 gpd recirculation rate.

Underdrain facilities beneath the sludge drying beds collected filtrate from wet sludge. Underflow from seven beds drained to either of two filtrate manholes, and from there to the wet well. The manholes were partially dammed and a sump pump placed in each. A standard water meter was installed in the discharge line of each pump to record bed drainage.

Two magnetic flow meters were added to the supernatant treatment system, one measuring raw flow coming in, the other measuring treated supernatant returning to the head of the plant. The difference between their cumulative readings gave the volume of precipitated sludge drawn to drying beds.

Three gas meters, one for each digester, were installed to permit accurate measurement of gas generated during sludge digestion.

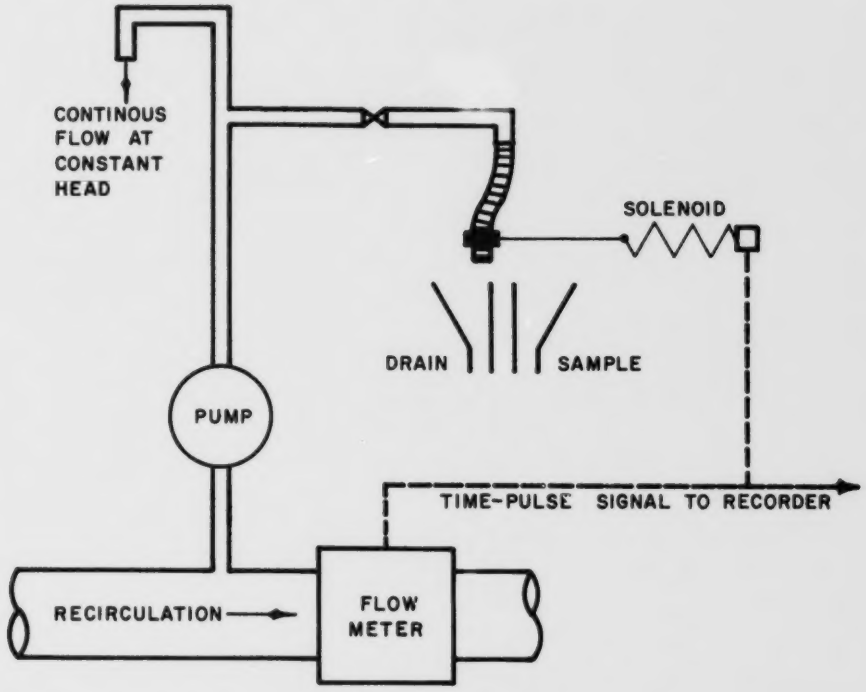

FIGURE 7. RECIRCULATION SAMPLER.
(Although a mechanical success, irregularities in quality of recirculation flow made this system a practical failure.)

MISCELLANEOUS IMPROVEMENTS

A small manually adjusted chlorinator had served the plant adequately for some years. At the time of the project it was replaced by an automatic 2000 ppd unit with compound-loop automatic controls. This changeover was undertaken more to improve overall operation than to modify the plant for chemical addition. After trial operations, the wastewater flow sensing leg was disconnected in the compound-loop control as chlorine flow in this installation could be adequately controlled by utilizing only the automatic residual analyzer.

A recording pH meter and a dissolved oxygen meter were installed to monitor plant influent and final effluent, respectively. Both supplied information valuable to the demonstration project, but neither would be necessary when modifying a plant to add chemical precipitation.

Ten small pipelines, mostly PVC, were installed at various locations around the plant. These delivered coagulant, polymer dilution water, diluted polymer, rinse water, and sample flows to designated receiving points.

A duplex strainer was added to the plant water system. This served to remove occasional large solids from treated effluent used for chlorine water supply and other similar needs. Also, a larger pressure tank and a new compressor were installed to upgrade the plant water system.

COSTS OF MODIFIED FACILITIES

Part of the Richardson treatment plant was built in 1953 at a total cost of $75,000, exclusive of land. In 1961, treatment facilities were enlarged to the present arrangement at an additional cost of $250,000, excepting land.

A new laboratory building was added in 1969 at a total cost of $33,000. This facility is considered an integral part of the treatment system, but perhaps one-third of its cost went to extra space for the demonstration project.

The laboratory was outfitted at a cost of $11,000. Furniture accounted for $2,000 of the total, and the $9,000 balance went for equipment and supplies. Some of the equipment including a $3,000 zeta meter, a $600 recording pH meter, a $700 recording dissolved oxygen meter, and some $700 worth of special glassware and chemicals would not have been required except for the demonstration project. The remaining $4,000 in laboratory facilities would have been spent just to support chemical coagulation in the treatment plant; major items included $800 for an advanced type jar test apparatus, an $800 analytical balance, and a $500 spectrophotometer.

If the laboratory had been built solely to support chemical coagulation in the treatment plant, it would have cost about $21,000 for the building and $6,000 for furniture, equipment and apparatus.

Modifications to the treatment plant exclusive of the laboratory building and its equipment came to a total cost of $53,000 distributed as follows:

Materials	$35,000
Labor	7,000
Supervision	3,500
Design and Misc.	7,500
TOTAL	$53,000

Construction labor and supervision were provided by city personnel, and figures cited include a factor for overhead. The high ratio of materials to labor relates to such expensive equipment as a $6,800 automatic chlorinator, two magnetic flow meters at $4,200 total, three fiberglass chemical tanks at $5,000 total, two polymer mixers at $2,200 total, and four chemical feed pumps at $6,800 total. All these items total $25,000 which is considerably more than it cost to install them. The $53,000 total is reduced to $38,000 when discounts for improvements related only to the demonstration project and not essential for chemical addition are made.

In summary, costs of all improvements related to chemical addition were about $65,000 in 1970 dollars.

PILOT TERTIARY TREATMENT UNITS

In mid-1971, pilot treatment studies were added as an adjunct to the plant-scale investigation. Facilities were provided to direct treated effluent to a multi-media granular filter and a carbon absorption system shown in Figure 8.

The filter consisted of 30 inches of mixed media housed in a vertical tube with a cross sectional area of 0.11 square feet. Media consisted of selected fractions of hard coal, sand, and garnet. Appurtenances included headloss gage, backwash piping, surface wash nozzle, and other items needed for a complete filtration system.

Four carbon columns were assembled in series. Each vertical column was 60 inches high and 0.0825 square feet in cross sections. The system was loaded with a total of 28 pounds of granular 8 x 35 carbon derived from lignite coal. Sampling points were provided for system influent and effluent and also between each column.

All pilot units were closed and operated under pressure. A supply pump delivered several gpm to the system. This was trimmed (by wasting) to 5 gpm/sq ft through the filter and carbon columns.

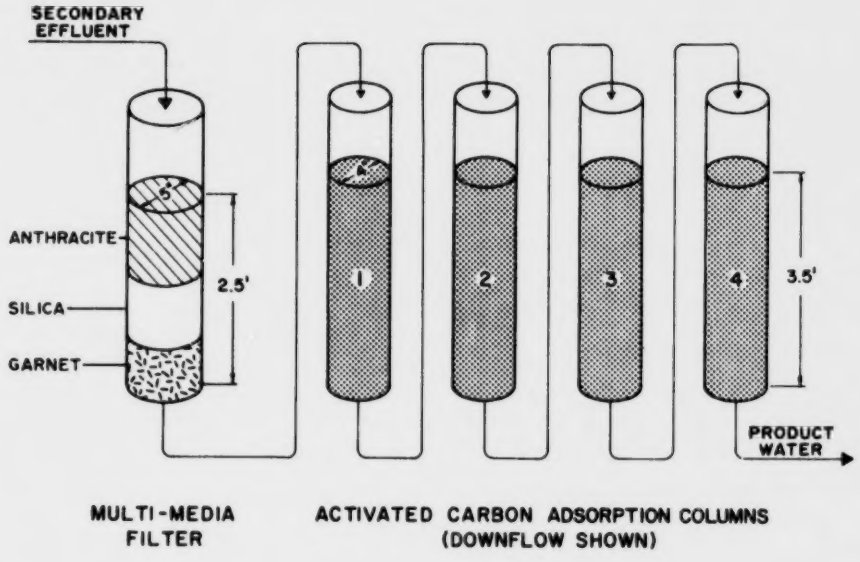

FIGURE 8. PILOT UNITS FOR FILTRATION AND ADSORPTION.
(Direction of flow in carbon columns was optional.)

Pilot units were provided without payment of rental. They were sheltered in a skid mounted metal building. The building, electrical service, and piping came to a total cash outlay of about $1500.

SECTION V

PLANT LOADING AND CONVENTIONAL PERFORMANCE

Richardson's wastewater treatment plant has historically operated at a higher degree of efficiency than is normally expected for the type of facility involved. This is partly because the system has been attended full time for a period of several years by qualified personnel who have given considerable attention to cleanliness, daily upkeep and maintenance.

Data were kept, throughout the course of this investigation, to develop broad overall values describing the character of the incoming wastewater. Quality of effluent discharged during conventional treatment (i.e., without chemical addition) was documented during baseline periods. During baseline periods the plant was operated without chlorination and without treatment of supernatant in order to produce an effluent characteristic of the main treatment units themselves.

Performance data were analyzed statistically to yield "averages" or a reliable measure of central tendency. In several cases, zero end constraint strongly affected families of data; in such instances the geometric mean was a better "average" than the arithmetic mean. Finally, it should be recognized that the reported values cover a broad period of time. Climatic extremes have evened out to provide a general overview, but the resulting values might not occur on any specific given day of operation. The results of these baseline studies are shown in Table 3.

TABLE 3

CHARACTER OF INFLOW AND CONVENTIONAL EFFLUENT
(mg/l unless noted)

	Influent	Effluent
Flow (MGD)	1.5	1.5
Suspended Solids	*155	*15
BOD_5	166	*20
Phosphorus (P)	*11	8
Total Kjeldahl Nitrogen (N)	24	12
Iron	*0.82	0.29
Aluminum	*0.25	0.10
Alkalinity	*180	175

*Geometric means, all other values are arithmetic means.

Detailed studies were also made of the rate of incoming phosphorus in the raw sewage. A typical diurnal variation in concentration (P in mg/l) is shown in Figure 9. The relatively constant concentration of phosphorus entering the plant on the day shown in Figure 9 could be highly misleading. When incoming phosphorus is converted to pounds per day, by combining concentration and rate of flow, a considerably more dramatic variation in phosphorus loading occurs (Figure 10). Additional studies of phosphorus removal during conventional treatment indicated a fairly consistent reduction of approximately 25% of the incoming phosphorus load.

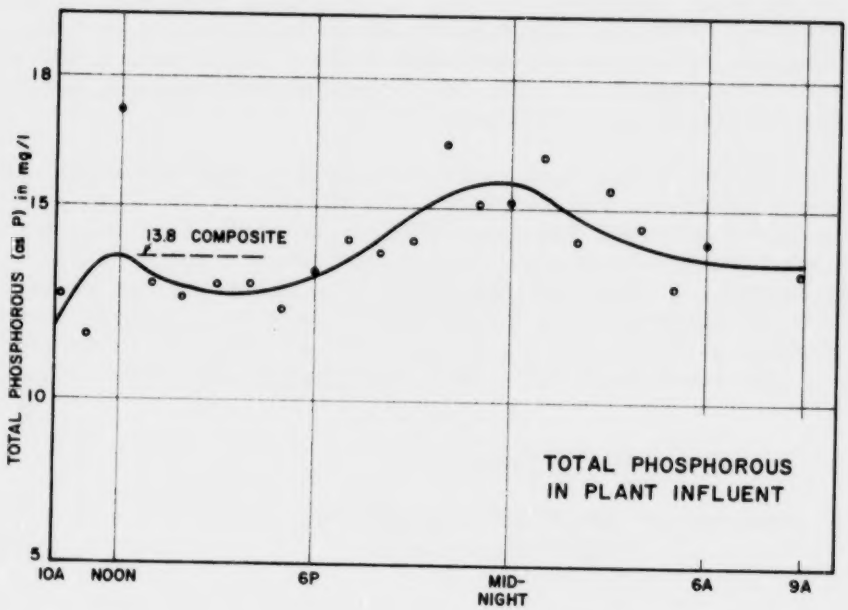

FIGURE 9. TYPICAL VARIATION IN INCOMING PHOSPHORUS CONCENTRATION. (Typical values did not have extreme diurnal variation.)

Prior to the baseline runs, both chlorination and supernatant treatment had been part of normal plant operation. The effect of chlorination on parameters in Table 3 was hardly discernable. However, supernatant treatment, as described before, did have a beneficial influence on overall plant performance.

In the Richardson operation, supernatant is normally drawn from all digesters on two days each week, sometimes one day only. On those days, the

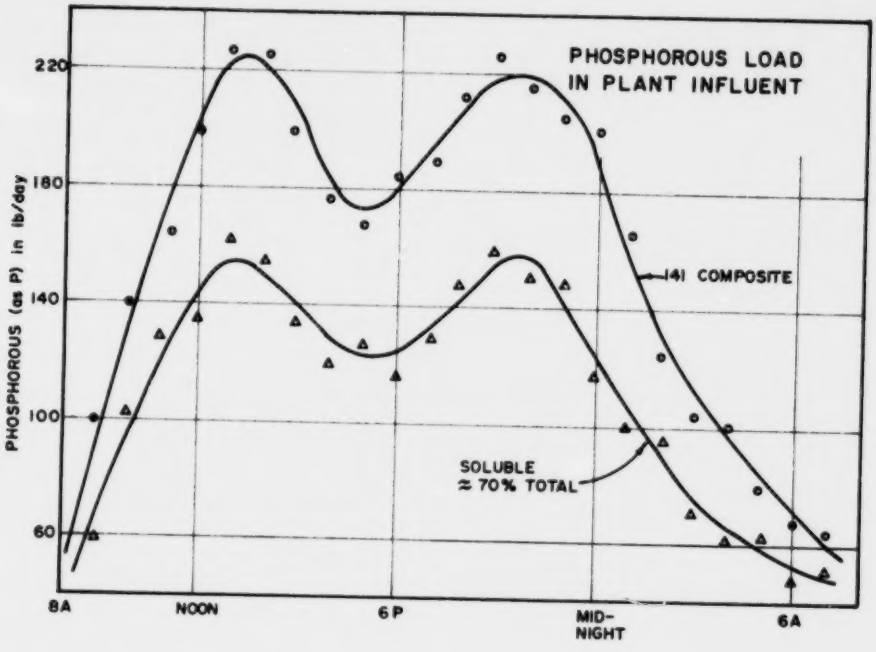

FIGURE 10. TYPICAL VARIATION IN INCOMING PHOSPHORUS LOAD. (When reexpressed as absolute load, the rate of incoming phosphorus fluctuated widely and was a major factor in control of chemical addition.)

amount drawn, some 2 percent to 3 percent of the total daily flow, is probably greater than handled in most plants; consequently, the liquor is rather dilute but if returned to the head of the plant untreated it has a pronounced effect on the overall system. The effects of batch alum coagulation, aeration, and settling on the quality of the supernatant are shown in Figure 11.

Actually, these results were taken before supernatant treatment was fully optimized. Efficiencies improved during the course of the study as continuous supernatant treatment was implemented, and treatment costs were reduced to approximately 0.1¢ per thousand gallons of raw wastewater flow.

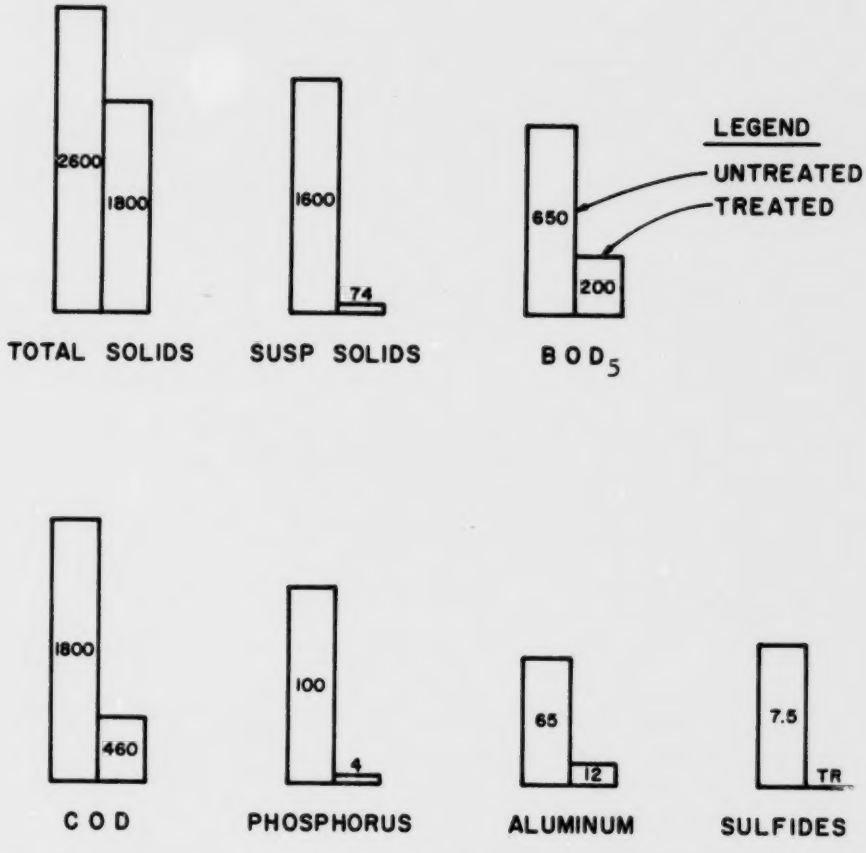

FIGURE 11. RESULTS OF ALUM TREATMENT OF DIGESTER SUPERNATANT. (Before and after values of pollutant concentrations (mg/l) show what can be accomplished for a cost of less than 0.2¢ per 1000 gallons of plant flow.)

In order to interpret plant performance during conventional operation, actual loadings on several of the major treatment units of this standard-rate trickling filter plant were calculated over a two year period of time. The results are shown in Table 4.

Notice that hydraulic loadings on the clarifiers were considerably reduced because the plant was deliberately operated at minimum recirculation. From the very outset, it was considered highly important to be able to operate clarifiers at average surface loading rates of 400 to 500 gpd/sq ft. In a similar vein, the rate of wastewater flow through the plant was normally kept less than or as near 1000 gpm as possible. In order to do this, operators took full advantage of storage capacity in the main wet well and incoming sewers to reduce peak sewage flows.

TABLE 4

LOADS ON BIOLOGICAL UNITS AND CLARIFIERS
(All calculated loadings exclude recirculation)

	Typical Design	Plant Design	Actual Observed
Trickling Filters			
lb BOD_5/1000 cu ft/day	10-20	10.4	14
mil gal/acre/day	2-4	*4	5
Clarifiers			
Primary: gpd/sq ft	900	*415	450
Final: gpd/sq ft	800	*410	440

*Designed to include 100% recirculation.

Finally, relatively stable flows allowed estimation of clarifier detention times at different flows, an important factor in predicting lag time through the plant. Hyperbolic equations describing assumed plug flow are plotted in Figure 12.

Although the plot is only an approximation of actual conditions (and this is further compounded when assuming plant detention time equals clarifier detention time, i.e., ignoring transit time in pipes, splitter and junction boxes, and through the filter media), it did prove most helpful in predicting period of passage through the system.

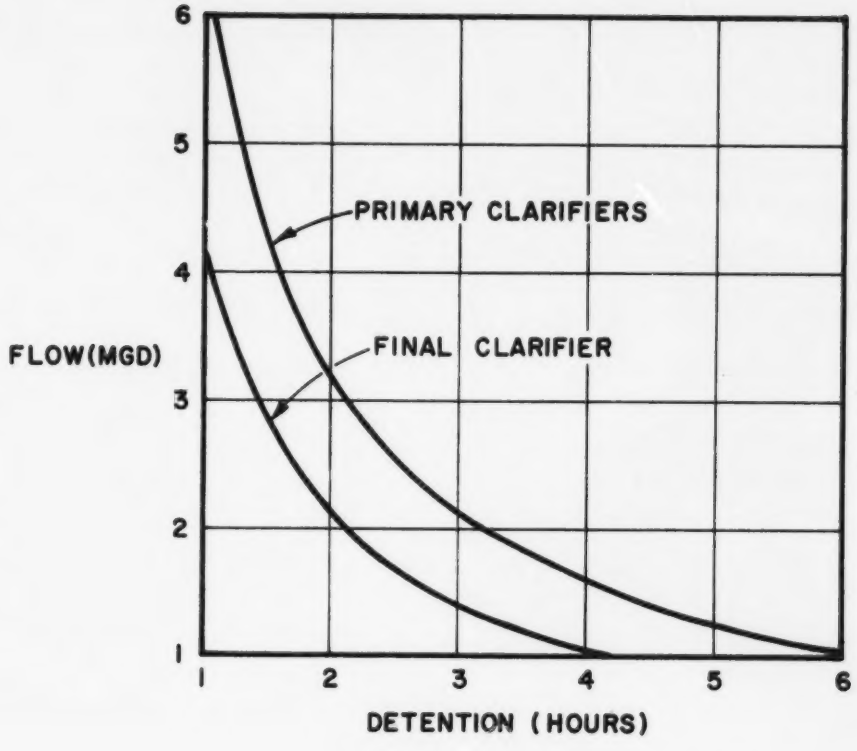

FIGURE 12. CLARIFIER DETENTION PERIODS AT DIFFERENT FLOWS. (At a given rate of flow, detention periods in clarifiers could be used to estimate travel time through the plant.)

SECTION VI

ALUM TRIAL

The initial trial efforts using liquid aluminum sulfate (alum) took place in the fall of 1970. The schedule called for a three-month period during which alum would be added just ahead of the final clarifier, or ahead of the primary clarifiers, or split-fed to both locations simultaneously. Figure 13 shows generally how time was allocated during this test period.

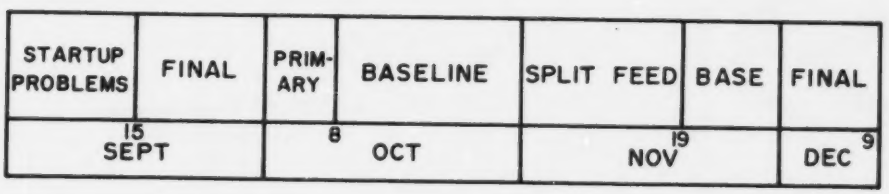

FIGURE 13. ALUM TRIAL ACTIVITIES, FALL 1970.
(Baseline periods were used to dampen effects of one arrangement before trying another.)

Alum was fed during some two-thirds of the period, the remainder of the time being taken up with startup problems and baseline runs. Supernatant was not treated during this phase and trickling filter effluent was not chlorinated.

A program of jar testing was carried out before plant scale additions began. Figure 14 shows a plot of phosphorus remaining versus alum fed after the samples had been stirred and settled. To reduce residual phosphorus to 0.5 mg/l as P, a metal dose of two moles aluminum per mole phosphorus was predicted from the jar testing, and this was reasonably close to what was found in plant-scale operations.

Typical startup problems delayed progress during the early part of this test period. Usable data were not generated during the first two weeks. Data taken from that point on is considered reasonably valid and representative of plant-scale performance; however, plant operations were

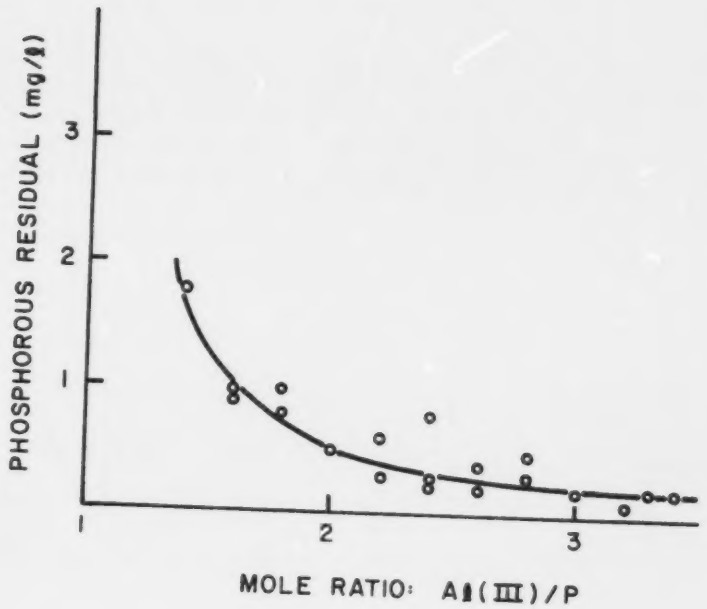

FIGURE 14. JAR TESTS OF PHOSPHORUS REMOVAL WITH ALUM. (Raw plant inflow was treated and settled, then analyzed to yield results shown here.)

evolving towards fixed operating techniques during this period so there is some trending in the records.

Physical startup problems involved repair of leaks in pipelines, recalibration of chemical delivery systems, modification of original treatment equipment to improve its performance, and other physical improvements. Careful observation during this initial chemical feed period resulted in further modifications to maximize utilization of existing treatment facilities as illustrated in the following example. When alum was fed to wastewater, the resulting floc served as a highly visible tracer of hydraulic patterns within settling basins. During dosage to the primary clarifiers, it became apparent that one of the three suffered very poor inlet distribution. Inlet baffling was designed and installed within a period of two or three days and the situation was brought under control. However, this occurred during the second month of the three-month alum

trial because the hydraulic shortcomings in the primary were not apparent during the first month when alum was being fed ahead of the final clarifier.

Adjustments in operating technique were also made during this period. A typical change was made after observing plant operations illustrated in Figure 15. When the alum feed rate was adjusted only twice during a 24-hour period, the resulting effluent phosphorus concentration ranged out of control during the evening peak load. This situation was corrected by introducing a feed schedule involving four rate changes per day, and finally five changes per day, both of which gave considerably better performance even though the total gallons of chemical fed per day were the same. Eventually, the standard operating practice was to change feed pump settings four times per day according to a fixed schedule.

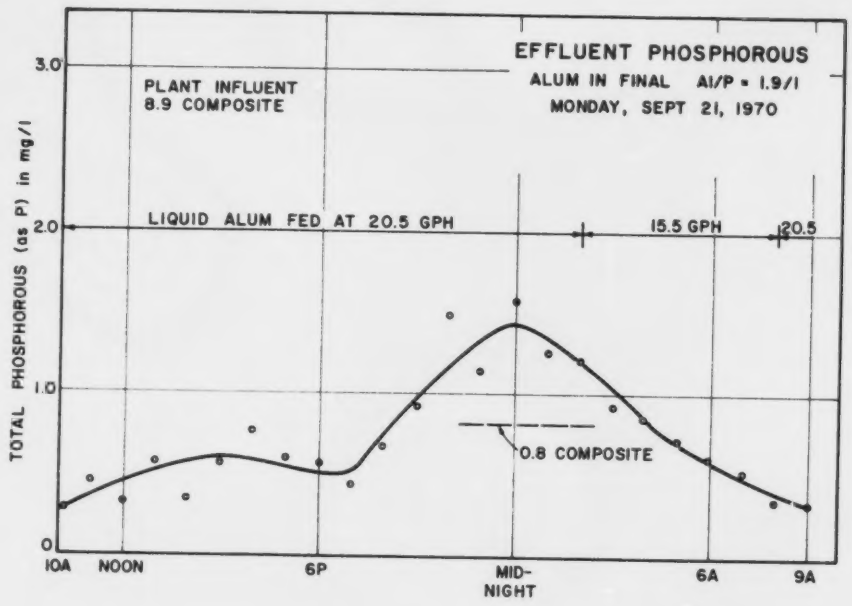

FIGURE 15. PLANT PERFORMANCE WITH TOO FEW ALUM FEED ADJUSTMENTS. (Effluent phosphorus peaked sharply when underdosing developed.)

During the first week or two of chemical treatment, it was assumed that a daily composite sample of plant effluent would provide sufficient

information for adjusting chemical feed rates. It became readily evident that this was not the case. Hourly grab samples were thus taken around the clock from the final clarifier effluent trough, analyzed for total phosphorus, and the hourly concentrations plotted for each 24-hour period. Review of these daily charts was the only manner in which sensitive control of chemical treatment could be assured.

Since the total pounds of phosphorus coming into the plant each day could not be predicted beforehand, incoming phosphorus load was estimated and chemical dosage was set to meet a pre-selected mole ratio of metal to phosphorus. A given feed rate was maintained for at least four or five days and, although the mole ratio would vary, it stayed generally within the range desired.

Chemical feed produced a heavy blanket of floc in the clarifier following the point of addition. The appearance and importance of this blanket was most impressive. A blanket was invariably present during high efficiency performance. This observation led to a major change in recirculation of treated effluent and settled sludge from the bottom of the final clarifier. For years, something near one MGD of recirculation was brought back to the head of the plant, mainly during late night hours. During chemical feed, however, this heavy recirculation almost totally evacuated the floc blanket by the following morning. As the incoming morning phosphorus load began to peak, the chemical feed rate would be raised. Contents of the clarifier would become turbid and diffuse until after mid-day. Effluent quality would temporarily deteriorate to a level less than satisfactory to meet project objectives. Despite (or because of) these circumstances, a floc blanket would begin to develop and by approximately 6 P.M. both the blanket and the efficiency of treatment would be highly developed.

It was also determined that a high recirculation rate was not essential to operate the rest of the treatment plant. Even during late night hours, there was sufficient incoming sewage to supply adequate flow to the entire system on a once-through basis. It was at this point that the timeclock-actuated intermittent recirculation system was installed and used from then on.

The workload involved in phosphorus analysis and the demands involved in sampling effluent every hour around the clock proved a powerful stimulus in automating this test. A Technicon Auto-Analyzer was made available on a loan basis from the U. S. Environmental Protection Agency. It was specially adapted for determination of total phosphorus in a continuous sample stream of final effluent water. The performance of the automatic analyzer proved highly reliable and test results were both accurate and repeatable. From the day the automatic system was installed it became an important focal point in control of plant operations.

Another dramatic performance characteristic in the final clarifier was never realized before advent of chemical addition. This involved the effect of wind on hydraulics through the vessel. When wind velocities

reached or exceeded 20 mph, floc in the final clarifier was blown to the downwind side of the tank and over the weir at that point. Under these circumstances, the floc was considered a near-perfect tracer. Therefore, it was concluded that high winds literally pushed water along with them and caused high weir loadings on the downwind side of the final clarifier. This occurred to a much lesser extent in the primary clarifiers, probably because of their smaller size.

CHEMICAL FEED PRECEDING FINAL CLARIFIER

Figure 16 shows one of the better early days when alum was being injected ahead of the final clarifier. Plant flow was 1.75 million gallons during this day and recirculation was held at 100,000 gallons.

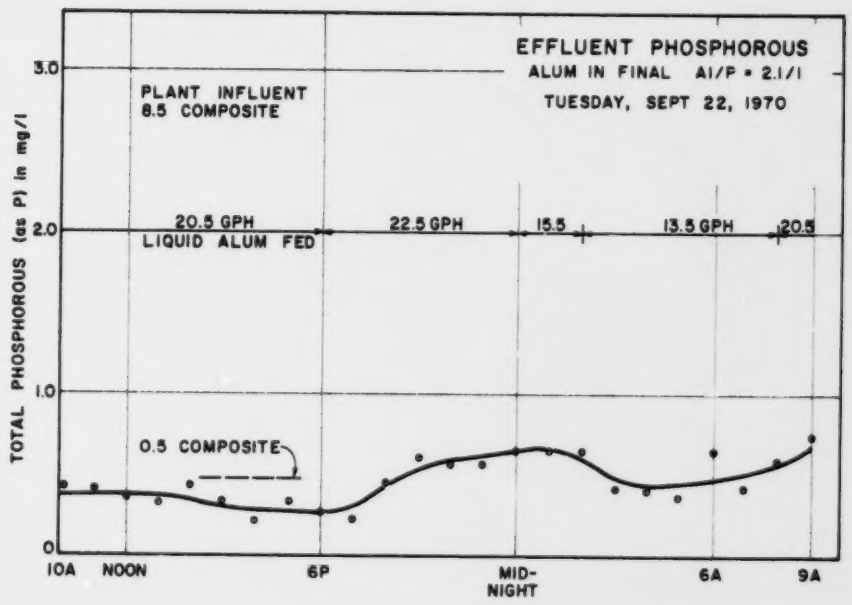

FIGURE 16. PLANT PERFORMANCE AFTER ADJUSTMENT OF ALUM FEED RATES. (This improved profile occurred the day after poor performance shown in Figure 15, even though the total quantity of alum fed per day was unchanged.)

The floc that developed on this particular day was large and heavy. On earlier days in the run, pin-point floc, appearing exactly the same as found in water treatment plants, was produced. The undesirable pin-point floc characteristic ceased when the chemical feed pattern was properly established.

Figure 17 summarizes plant performance during this entire period.

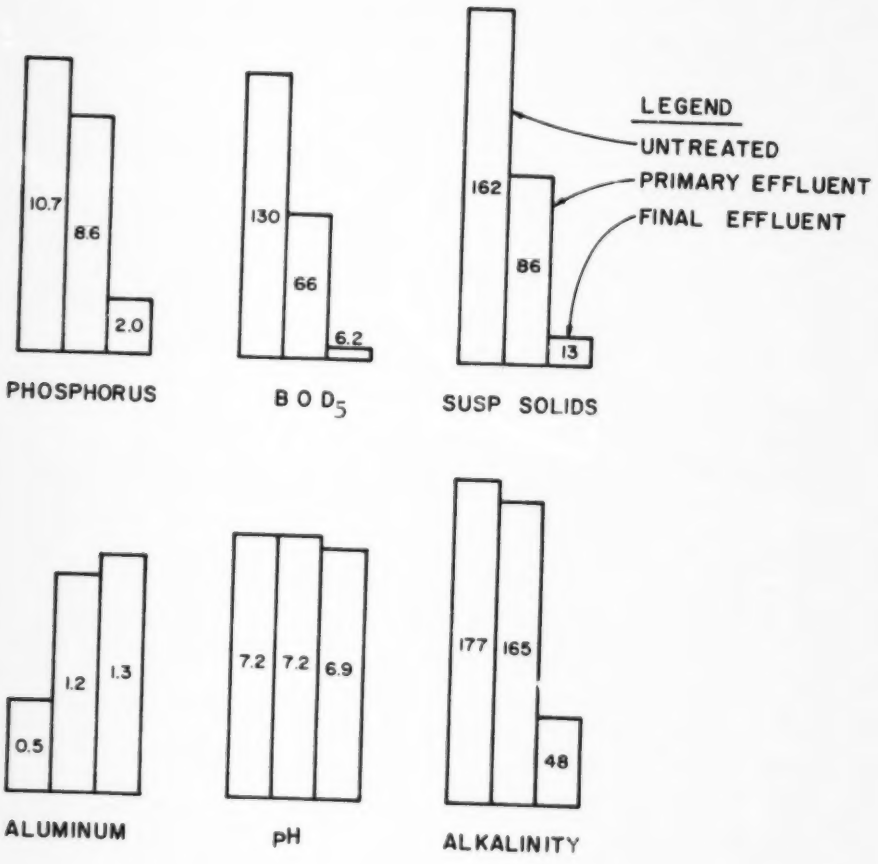

FIGURE 17. RESULTS OF ALUM FEED PRECEDING FINAL CLARIFIER.
(Values are mg/l, except pH.)

Although effluent phosphorus levels were not consistently reduced to desired low levels, effluent BOD_5 and suspended solids stayed under excellent control throughout the entire period. Other parameters seemed reasonable.

CHEMICAL FEED PRECEDING PRIMARY CLARIFIERS

After 15 days of alum feed preceding the final clarifier, the point of chemical application was changed to just ahead of the primary clarifiers. Figure 18 summarizes phosphorus removal for a typical 24-hour period of feeding alum to the primary clarifiers. Performance fell below that experienced in feeding to the final. Also, in this case the alum feed rate had not been trimmed quite enough to level out an evening hump.

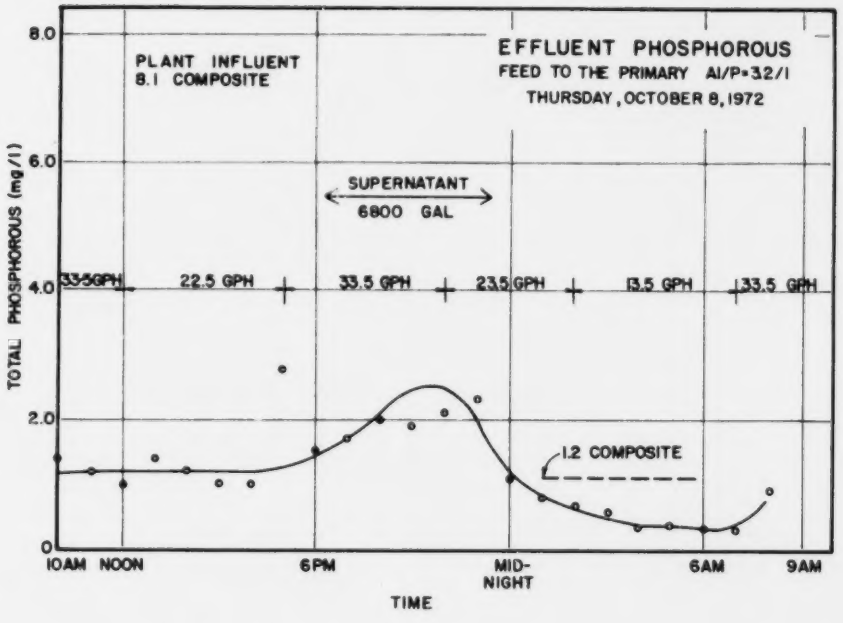

FIGURE 18. EFFLUENT PHOSPHORUS PROFILE WHEN FEEDING ALUM AHEAD OF PRIMARY CLARIFIERS. (Even ignoring untreated supernatant, the results of this approach were not outstanding.)

Figure 19 graphs the overall performance of the treatment plant when liquid alum was injected into untreated wastewater. These figures summarize the eight-day October trial period. Although there was not sufficient data to yield extensive information, these bar graphs reflect overall operation of the plant at this time.

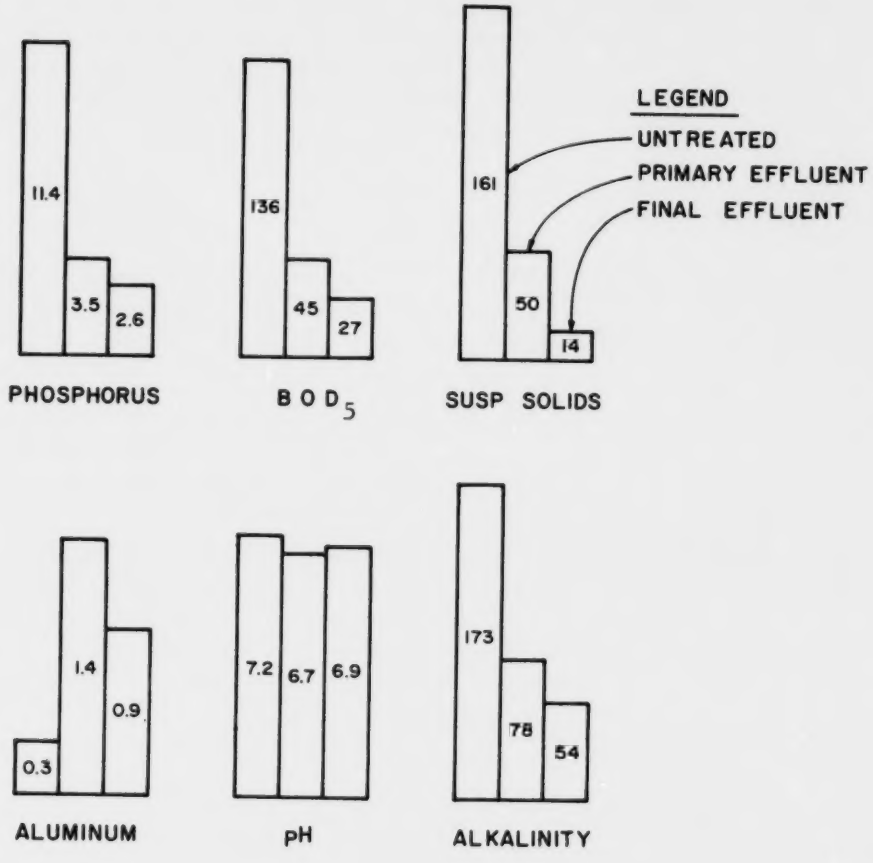

FIGURE 19. RESULTS OF FEEDING ALUM AHEAD OF PRIMARY CLARIFIERS.
(Values in mg/l, except pH.)

One pronounced change observed during this feeding technique was a considerable increase in the volume of primary sludge produced. It appeared that some 50 percent more primary sludge was produced than when the plant was run in a conventional mode without any chemical addition. All three primary clarifiers contained highly visible and massive blankets of sludge. These zones of compacting sludge sometimes reached as high as the effluent weirs, although generally the sludge could be held down and moved from clarifiers into the digestion compartments.

Primary effluent was murky or turbid most of the time and this characteristic persisted in the wastewater all the way through the final clarifier. The difference in effluent suspended solids in this phase of the trial and in the preceding phase was not very great, but there was definitely a difference in the gross appearance of the water. Unfortunately, an adequate turbidimeter was not available at this point in the project so valid information on this characteristic could not be documented.

From time to time it was possible to see a wispy floc blanket in the final clarifier. This blanket had the same general shape and size as the dense blanket produced when alum was fed at that point; however, in this case, the blanket was very diffuse and appeared essentially as a ghost of the highly developed blanket seen earlier.

After a week of feeding alum to the primary clarifiers, problems developed in the sludge digesters. These digesters were not accessible so that the operators could not make a careful study of the situation at several depths. However, it appeared that stratification developed in the digesters and involved two layers of solids; one heavy large layer on the bottom, and one fresh light layer at the top. They were separated by a layer of relatively clear supernatant. This assumption could be demonstrated fairly well by observation and tests as liquid was withdrawn from digester supernatant zones. In addition, as the upper layer grew the supernatant became darker, its solids increased to a one percent concentration, and its hydrogen sulfide concentration increased.

This distressing situation developed in the short period of just slightly more than one week. After some discussion, it was concluded that sufficient data had been collected to indicate general performance during this phase. More to the point, it appeared there was real danger of loss of control of the digestion operation. Therefore, this phase was terminated and the entire plant was put on a restabilization baseline operation. Contents of the digesters were mixed with recirculating pumps during the next two weeks. Digestion returned to normal and there was never a significant recurrence of this problem in all of the months that followed.

In this phase, records show that the mole ratio of alum to phosphorus was frequently more than two, yet effluent phosphorus concentrations were consistently greater than one mg/l. To match performance achieved when feeding ahead of the final clarifier, some one-third more alum was required in the primaries. When mole ratios approached three, final

effluent phosphorus was finally driven down to about one mg/l, but of course chemical costs were quite high at this point and the digester problems already noted began to develop.

SPLIT FEEDING TO PRIMARY AND FINAL CLARIFIERS

Phase three of the alum trial involved feeding chemical simultaneously to both primary and final clarifiers. The operation began by feeding 100 percent to final clarifier; then the feed was split and an increasing fraction was fed to the primary clarifiers while keeping total gallons fed per day the same. Two days of 100 percent feed to the final clarifier re-established chemical treatment following baseline operations in the preceding phase. Then, for ten days, 80 percent of the chemical was dosed to the final clarifier and 20 percent to the primary clarifier. At mole ratios near 2, the results were good. Phosphorus on a typical day shown in Figure 20 was reduced from 9.2 to 0.3 mg/l with recirculation held at less than 100,000 gallons per day. The results of this trial were as good or maybe slightly better than those gotten when 100 percent final feed was employed.

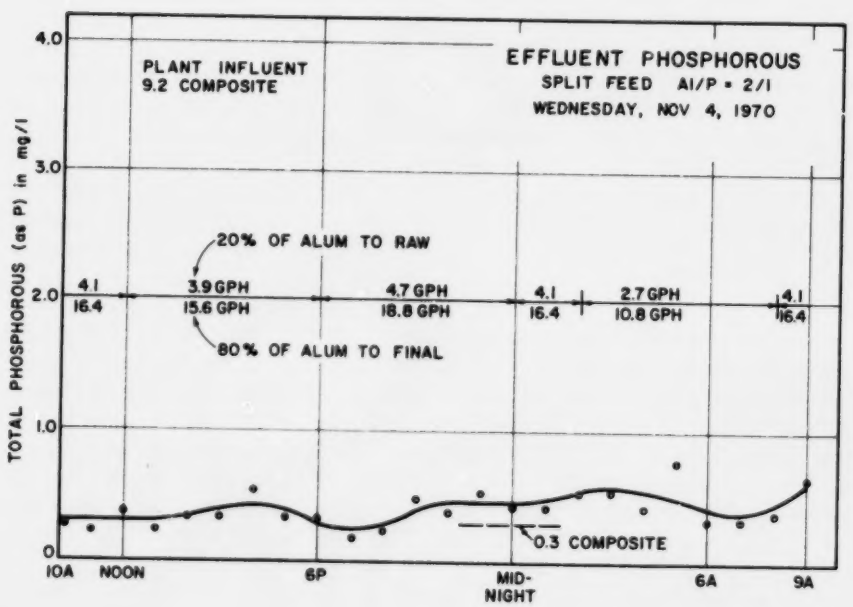

FIGURE 20. EFFLUENT PHOSPHORUS PROFILE DURING SPLIT FEED OF ALUM. (This approach was as effective as feed to final, but required more effort to control.)

Next, a 70 percent final, 30 percent primary split was tried. The results were not as good, over a 5-day period, as when a greater fraction of chemical was fed to the final clarifier. Phosphorus concentration in the effluent rose to as high as 1.2 mg/l during part of this effort, due partly to a 15 percent cutback in total gallons of alum fed per day. This was done in an attempt to see if economy in chemicals would compromise plant performance, which it did. On the eighteenth day of split feeding, there were early but unmistakable signs that digester problems were developing in a way similar to those reported under 100 percent feed to the raw inflow, necessitating termination of the trial at that point.

GENERAL OBSERVATIONS

As reported, there were indications that the sludge digestion operation was experiencing distress during much of this phase. However, methane concentration remained consistently above 80 percent and gas production remained vigorous. Alkalinity in supernatant would be near 1,000 mg/l at the beginning of a draw; after 15,000 gallons it would drop to 500 mg/l, indicating dilution by wastewater being drawn from the clarifier to the withdrawal area.

The concentration of digested sludge dropped from 8 to 6 percent during the alum addition trial and there was an increase in the volume of sludge produced. However, digested sludge dried quite rapidly, cracking in about three days instead of the usual six or seven. Total drying time was cut from the previous average of about 22 days to something on the order of 8 to 10 days. The sludge dried in larger pieces and had a light grey film over the top surface when it was dried.

Coliform organisms were present in the final effluent within the range of 1,000 to 10,000/ml when conventional treatment was employed and chlorination was temporarily discontinued. When using alum, and still without chlorination, plant effluent showed never more than 800 total coliforms/ml, nor more than 30 fecal coliforms/ml.

To achieve the kind of results shown in Figure 17 when feeding alum in the final clarifier, chemical cost approximated 4.6¢/1,000 gallons of flow. This degree of treatment, indicated in Figure 19, while feeding alum to the primaries was obtained at an alum cost of 5.7¢/1,000 gallons. Both figures reflect a 10 percent lower delivered chemical cost than the rate paid in later months.

Alum feed to the final clarifier was reinstituted during the early part of December. This was done for two reasons: (1) to collect additional data to supplement the rather short trial made in September and (2) to determine whether cooler water temperatures had a noticeable effect on treatment. The December experience was in no particular way different from the results obtained in September so the two groups of data were ultimately combined and are reflected in Figure 17.

SECTION VII

IRON TRIAL

Liquid ferric chloride addition was evaluated during the first three months of 1971. The iron compound was actually fed and recorded a total of 80 days over that period of time. Figure 21 shows the metal salt was dosed either to the final clarifier or to the primary clarifiers. Split feed was not considered necessary to study the basic characteristics of the iron salt as a chemical additive. Digester supernatant was not treated and effluent chlorination was not practiced during the iron trial runs.

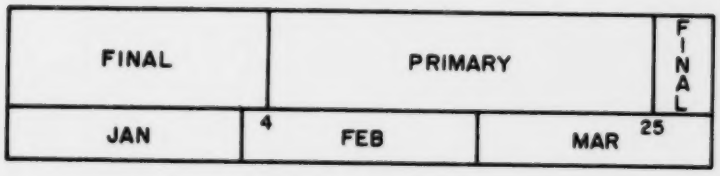

FIGURE 21. IRON TRIAL SCHEDULE, WINTER 1971. (Chemical was fed either preceding final clarifier or primary clarifiers. Split feed was not practiced in this run.)

Outside temperatures were frequently near freezing during this season of the year. Under these conditions, incoming wastewater temperature decreased from slightly less than 70° F to near 60° F after passing through the trickling filter and final clarifier. While these temperatures are not extremely cold, they were felt important enough to receive due consideration.

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Figure 22 summarizes the results of jar tests with ferric chloride on raw wastewater. In this bench scale trial, the iron salt decreased total phosphorus residuals in the decant to less than one mg/l when the metal to phosphorus mole ratio was 1.5 or greater.

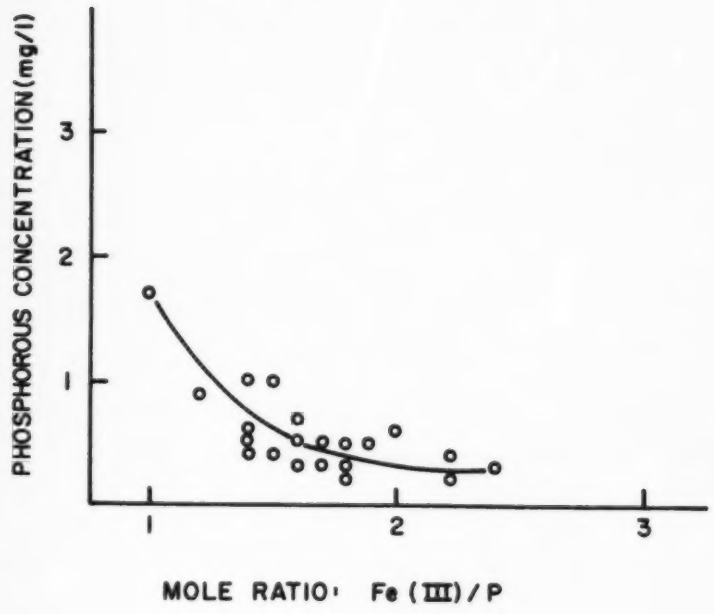

FIGURE 22. JAR TESTS OF PHOSPHORUS REMOVAL WITH FERRIC CHLORIDE. (After treating and settling, results similar to alum treatment were recorded.)

Plant performance did not parallel jar test results as it did with aluminum, however. Figure 23 shows that more than a two to one ratio of metal to phosphorus was required to even approach one mg/l total phosphorus in the plant effulent. This shortcoming was one of the dominant characteristics of this trial period and will be discussed in more detail later.

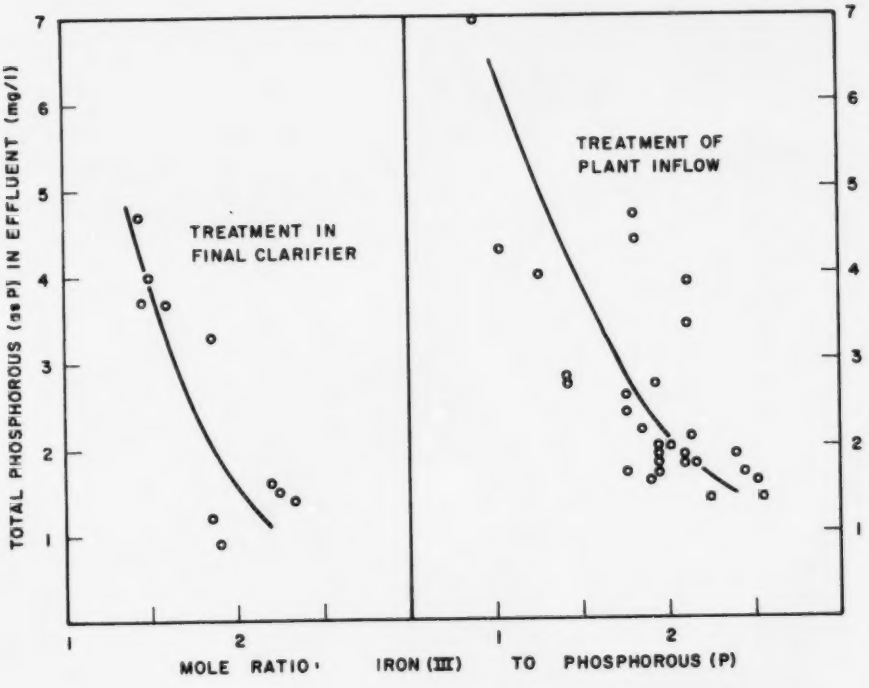
TOTAL PHOSPHOROUS (as P) IN EFFLUENT (mg/l)
TREATMENT IN FINAL CLARIFIER
TREATMENT OF PLANT INFLOW
MOLE RATIO: IRON (III) TO PHOSPHOROUS (P)

FIGURE 23. PHOSPHORUS REMOVAL TRENDS WHEN FEEDING FERRIC IRON TO FINAL AND PRIMARY CLARIFIERS.
(Dosage requirements proved to be higher than predicted in jar tests.)

Figure 24 indicates, in generalized figures, that phosphorus, BOD_5 and suspended solids were reduced to fairly low concentrations for the type of treatment plant involved when iron was dosed to the final clarifier. However, these were far greater than the concentration levels desired, and in the case of effluent BOD_5 and suspended solids actually represent a deterioration from conventional treatment without chemical addition. Further, iron and chloride concentrations were high enough to be considered undesirable. Alkalinity levels were appropriate for the chemical additive being administered.

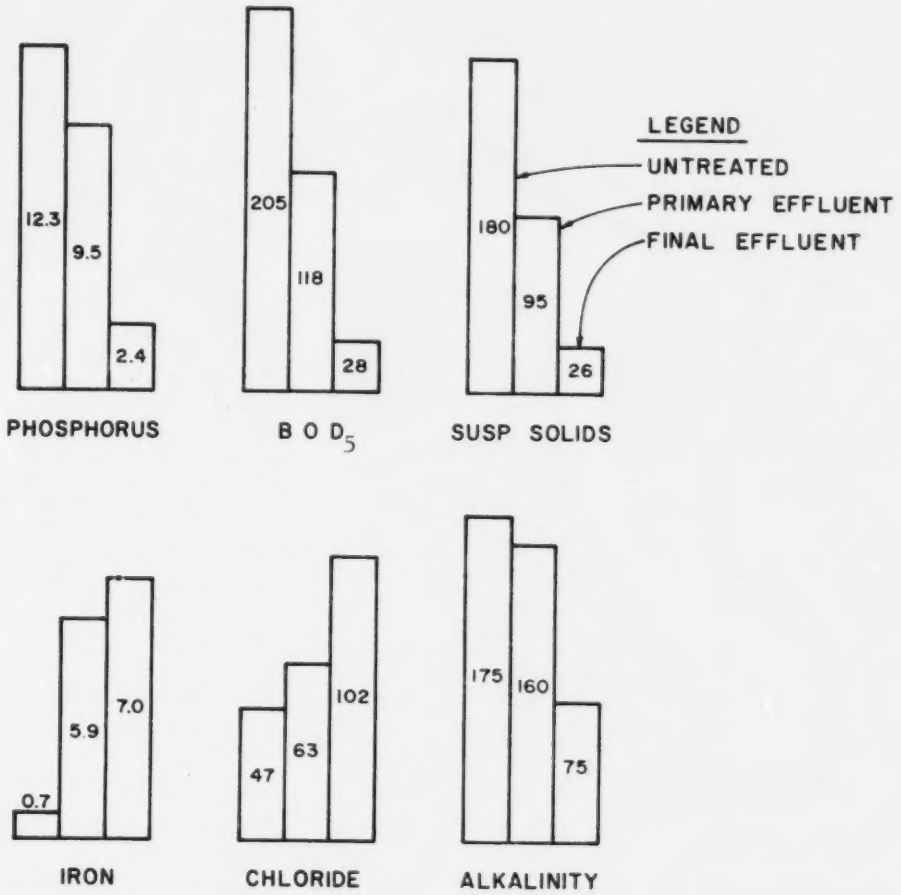

FIGURE 24. RESULTS WHEN FEEDING IRON PRIOR TO FINAL CLARIFIER.
(Values in mg/l, except pH.)

When iron salt was added ahead of the primary clarifiers, significant reduction in iron concentration resulted as shown in Figure 25. Final effluent phosphorus, BOD_5, and suspended solids concentrations were similar to those seen when iron was fed to the final clarifier. Alkalinity concentrations decreased sequentially through the plant as expected.

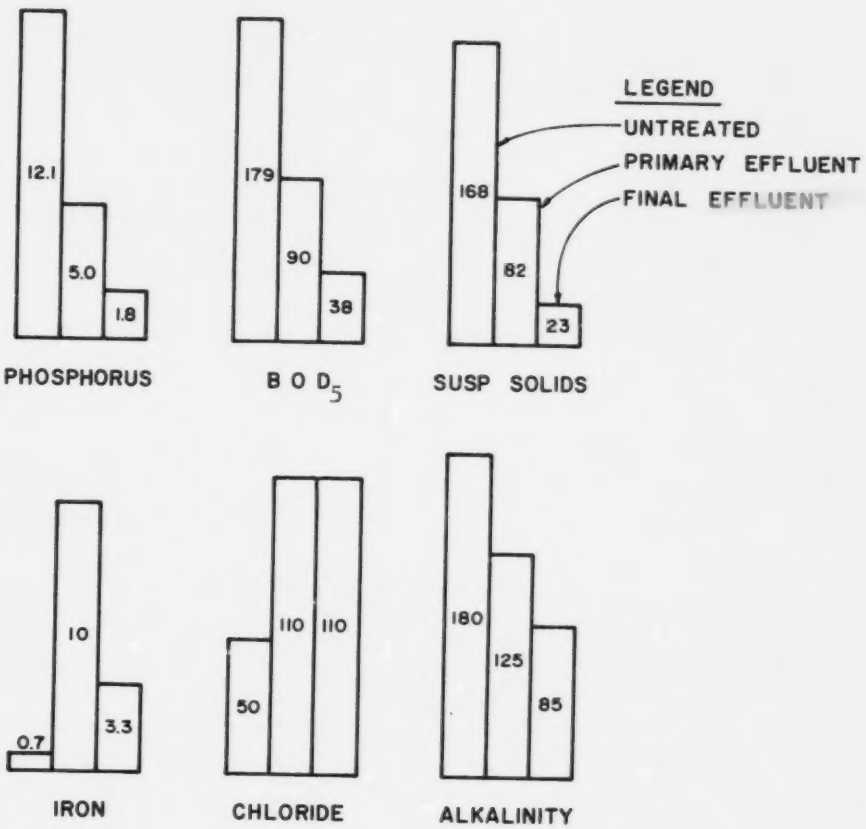

FIGURE 25. RESULTS WHEN FEEDING IRON PRIOR TO PRIMARY CLARIFIERS. (Values in mg/l, except pH.)

A more sensitive display of some of these features is provided by hourly profiles of typical treatment days. Figure 26 shows such a profile for a typical day when iron was added to the primary clarifiers. The mole ratio of metal to phosphorus was 1.9, and the resulting cost was 5¢/1000 gallons treated. Total flow to the plant and effluent recirculation on that day were 1.3 million gallons and 90,000 gallons, respectively. Effluent iron concentration was near 3 mg/l for much of the day. Note that the profile of the iron concentration very closely parallels the profile of effluent phosphorus, which averaged 1.6 mg/l in this instance.

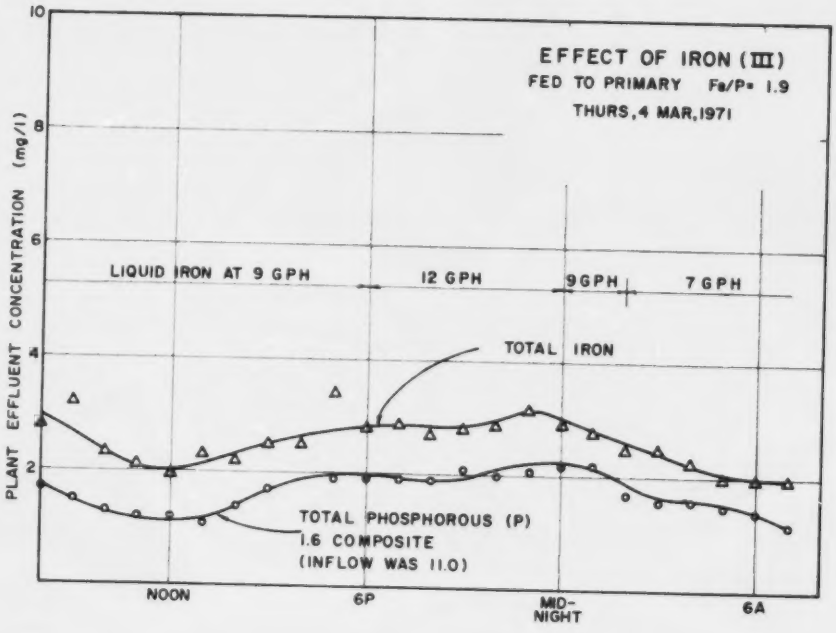

FIGURE 26. PHOSPHORUS AND IRON LEAKAGE WHEN FEEDING AHEAD OF PRIMARY CLARIFIERS.

Figure 27 summarizes a typical day when iron was being fed to the final clarifier. In this case, the mole ratio was somewhat higher at 2.33. At a total plant flow of 1.2 MGD, this high chemical feed rate boosted the cost to 6.4¢/1000 gallons of flow. Even so, effluent phosphorus was determined at 1.4 mg/l in the composite sample taken that day. Concurrently, the effluent iron escaping the final clarifier had a composite value of more than 6 mg/l.

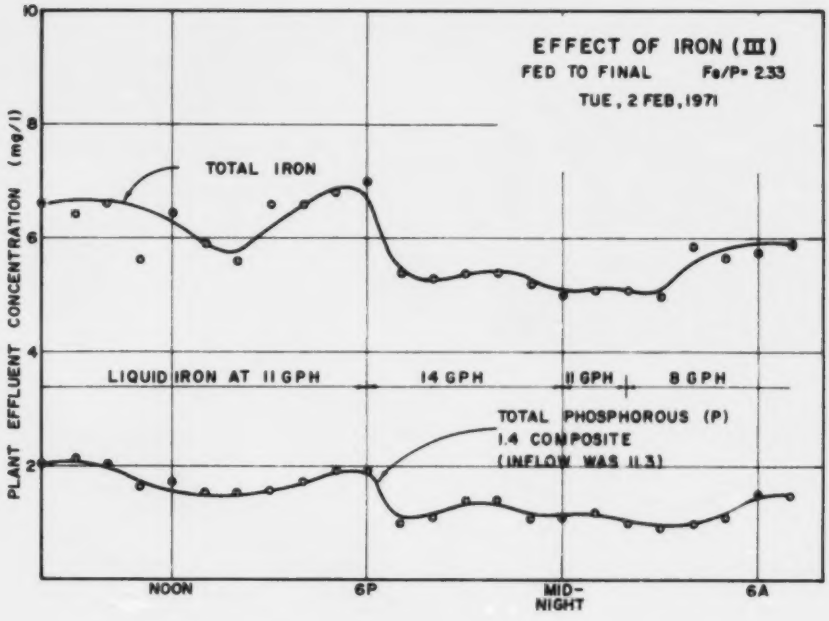

FIGURE 27. PHOSPHORUS AND IRON LEAKAGE WHEN FEEDING AHEAD OF FINAL CLARIFIER.

This distressing matter of iron leakage is displayed in more detail in Figure 28. Clearly, when ferric chloride was injected prior to the final clarifier, considerably more iron escaped in the effluent than when treating the raw wastewater ahead of the primaries.

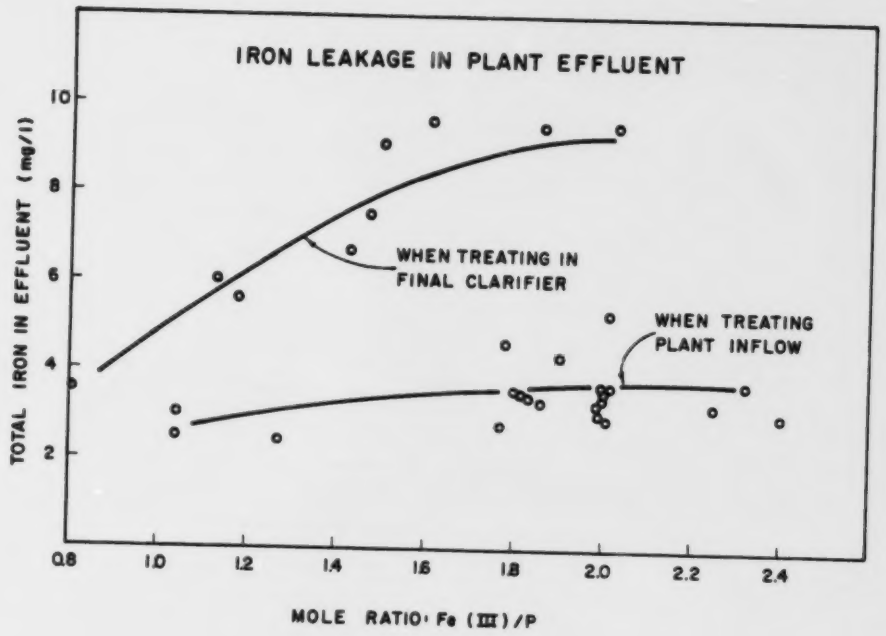

FIGURE 28. SUMMARY OF IRON LEAKAGE DATA. (Most escaping iron was in colloidal form, and it caused a distinct red color.)

Data from the lower curve are replotted by themselves in Figure 29. In addition, the results of four days efforts with a polyelectrolyte are also superimposed on the graph. During this brief period, iron dosing to the primaries was continued while the polyelectrolyte was added to the final clarifier. There is clear indication the polymer did reduce iron leakage by improving entrainment and settling of colloidal iron.

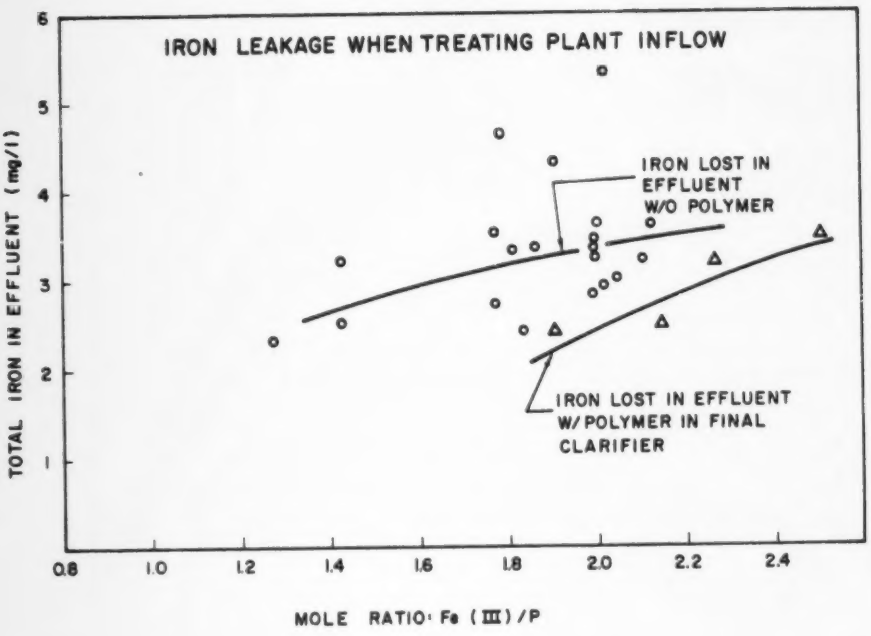

FIGURE 29. REDUCTION OF IRON LEAKAGE WITH POLYMER. (Efforts to optimize polymer feed were not carried further once it became clear that benefits were possible.)

Even without use of polyelectrolytes, iron levels were reduced sequentially throughout the plant when ferric chloride was fed ahead of the primary clarifiers (Figure 30). Reductions were not sufficient, however, because effluent concentrations of 3.2 mg/l of iron still produced a distinct red hue.

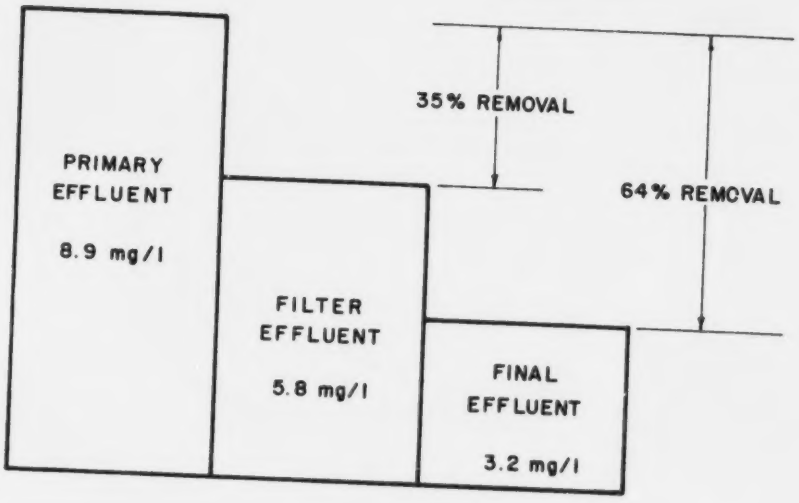

FIGURE 30. REDUCTION OF IRON LEAKAGE THROUGH TREATMENT UNITS. (Incoming wastewater had an iron level of 0.85 mg/l. Ferric chloride was fed just ahead of primary clarifier. Data are from a 30-day period.)

GENERAL OBSERVATIONS

Floc resulting from ferric chloride addition was smaller, denser and less gelatinous than floc produced from alum. As already indicated, however, effluent concentrations of several pollutants were not reduced to the desired levels. This occurred in spite of dry weather which decreased plant flow by some 20 percent. Average flow during the iron addition trial was 1.3 MGD, and hydraulic loading rates throughout the treatment plant were reduced accordingly. It was felt that reduced wastewater flow, at least in some measure, compensated for lower wastewater temperatures encountered during this period.

Sludge digestion, although not supported by heating systems, continued vigorously during this period. Sludge solids concentrations stayed near six percent. The aluminum concentration in the sludge stabilized and began to taper off as older sludge was removed from the digestion systems. Iron concentration began to build in the digester solids.

After the alum sludge was substantially purged from the digesters, the digested sludge produced during iron addition dried noticeably better than digested sludge during aluminum addition. Dry weather drying cycles were on the order of 9 or 10 days for iron versus 10 or 12 for alum sludge. Supernatant during iron treatment was similar to that produced when adding aluminum.

When ferric chloride was added to the primary clarifiers, a red film was quickly established on the stones in the trickling filters. Some additional zoogleal film thickness had been noticed with aluminum, but iron film was thicker and more visible due to its distinctive color. The build-up apparently reached proportions where hydraulic action caused the slime to begin to break up and slough off. This was followed by a general sloughing of filter flora, an unusual event for this time of the year in this standard-rate trickling filter system. There was no clear evidence of subsurface ponding in either trickling filter, even in the smaller filter which contained smaller rocks.

In summary, chemical costs for iron addition were higher than when aluminum was fed, largely because higher metal to phosphorus mole ratios were required with iron. Despite the higher metal dose during the iron trial, effluent concentrations of pollutants were considerably higher than in the alum runs. Combining polymer feed to the final with iron addition to the primaries improved overall effluent quality, but not to a point to put iron in a competitive range with aluminum. This coupled with the persistent iron leakage led to the selection of aluminum as the chemical of choice for an extended plant run.

SECTION VIII

EXTENDED ALUM RUN

A pictorial graph of activities during this phase is shown in Figure 31. The extended alum run covered a total period of 11½ months. During the entire period liquid alum was fed into the treatment system just ahead of the final clarifier.

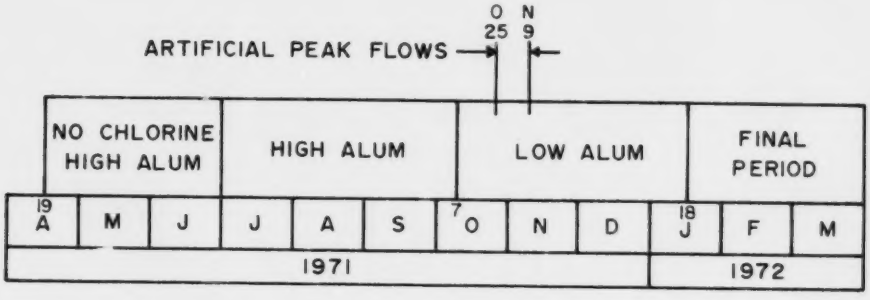

FIGURE 31. EXTENDED ALUM RUN ACTIVITIES, APRIL 1971-MARCH 1972. (During the entire year, alum was fed just ahead of final clarifier. Chlorination was deferred until July and supernatant treatment until August.)

Effluent chlorination was not practiced during the first three months of this phase. Supernatant was not treated during the first four months. In order to evaluate the effect of high flow rates, peak flow pumping was practiced about midway through the 11½-month extended run.

During the period designated High Alum, the aluminum/phosphorus mole ratio approximated 1.7/1.0. The ratio was decreased to about 1.5/1.0 during the Low Alum period.

During the last three months, shown on the graph as Final Period, the entire operation was optimized and much of the data taken then are given detailed attention in this section of the report.

The bar graphs presented in Figure 32 give generalized results of the treatment efforts during the entire 11½-month extended alum run. The

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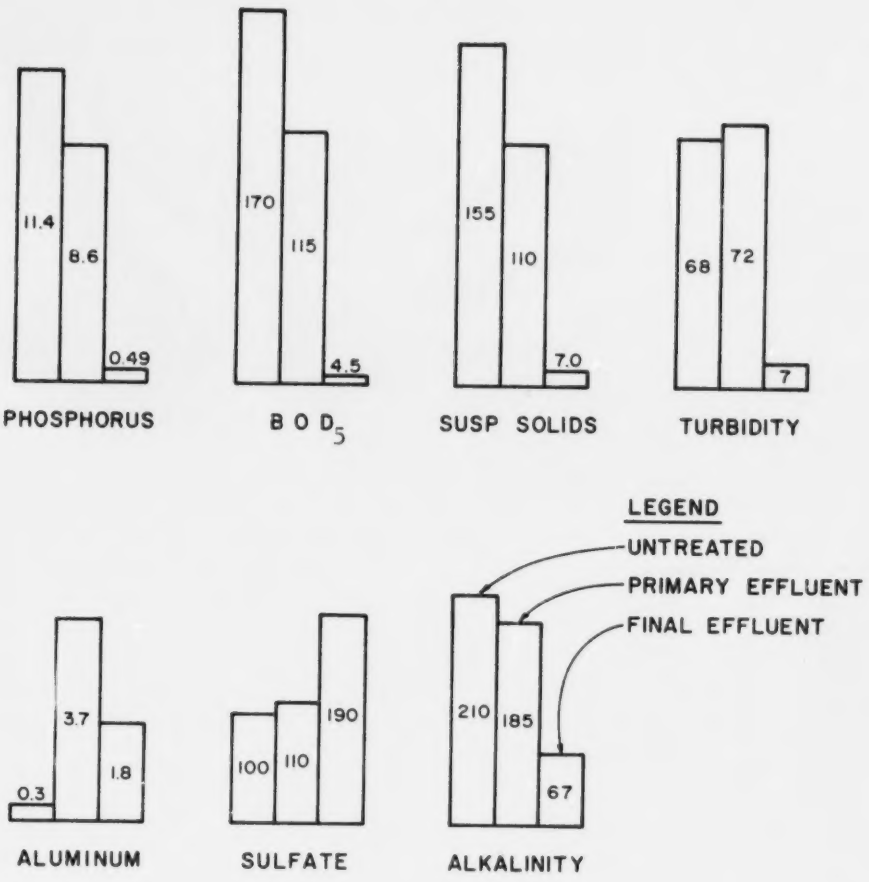

FIGURE 32. OVERALL PERFORMANCE DURING EXTENDED ALUM RUN. (Values (mg/l) represent operations during an 11½-month period.)

average mole ratio of Al/P during the entire phase was 1.6, resulting in a chemical cost of 5.1¢/1000 gallons of flow treated. Detailed daily and monthly average data for the extended alum run are given in Appendix C.

Flow during this period averaged 1.6 MGD. This resulted in overflow rates of 445 gallons per day per square foot in the primary clarifiers, and a corresponding figure of 420 for the final clarifier. Other pertinent data are shown in Table 5.

TABLE 5

PLANT PERFORMANCE DURING EXTENDED ALUM RUN

	Influent	Effluent
pH	7.2	6.7
Temperature (°F)	70's	60's
Dissolved Oxygen (mg/l)	0.2	7.2
Total Solids (mg/l)	690	475
COD (mg/l)	370	42
Ratio BOD_5/COD	0.46	0.11
Volatile Fraction, Suspended Solids	0.86	0.90

Long periods of stable operation were logged to develop the results which have just been presented. Figure 33 depicts a typical day when the entire system was under good control. Flow through the plant on that day was 1.38 million gallons; recirculation was 70,000 gallons.

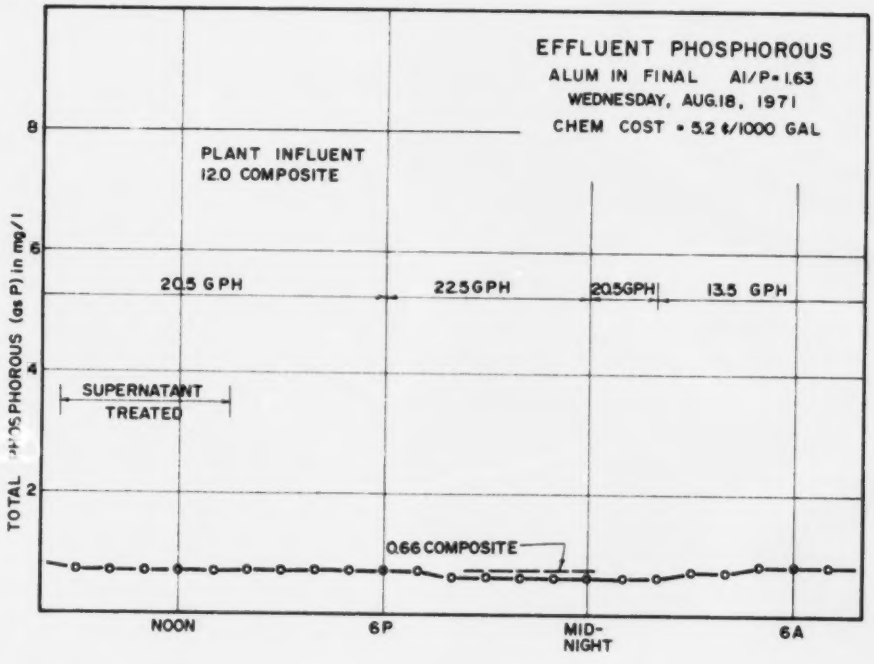

FIGURE 33. TYPICAL DAILY PERFORMANCE DURING OPTIMIZED CONTROL.

EFFECT OF SUPERNATANT TREATMENT ON PERFORMANCE

To achieve the kind of performance illustrated in Figure 33, supernatant treatment was required. Typical results when supernatant treatment was not treated are shown in Figure 34. In this instance, 30,000 gallons of untreated supernatant were returned to the head of the plant during the daylight hours. The result was a noticeable increase in effluent phosphorus commencing about seven hours after the onset of supernatant return and a relatively poor composite value of 0.8 mg/l effluent phosphorus for that day.

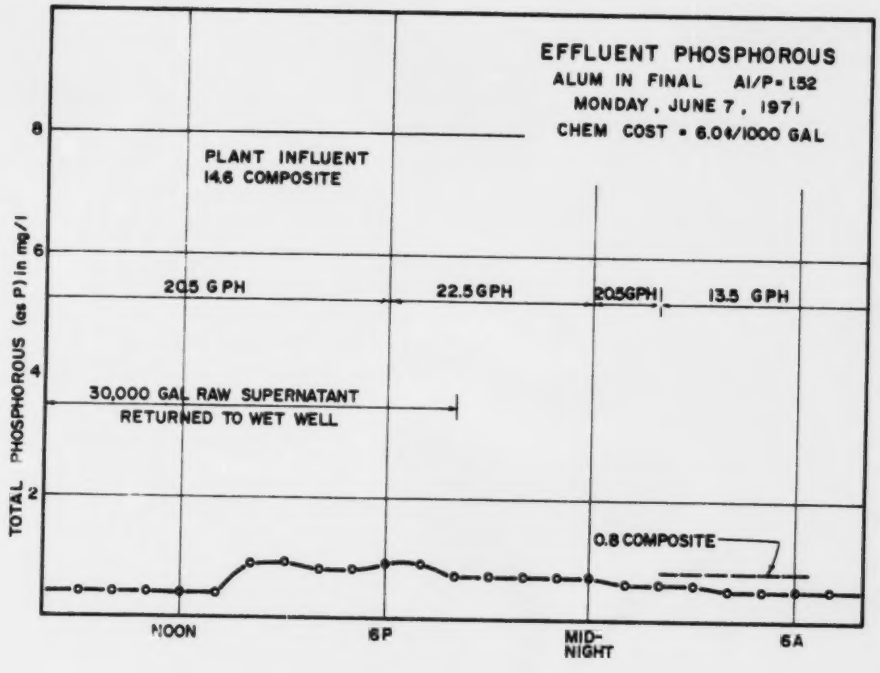

FIGURE 34. EFFECT OF UNTREATED SUPERNATANT ON PLANT PERFORMANCE.

If alum treatment of the main flow of wastewater had not been underway, the returned supernatant would have increased effluent phosphorus by about 2 mg/l above the conventional treatment effluent phosphorus level of 8 mg/l without supernatant return.

A combination of untreated supernatant and rainfall infiltration caused the situation illustrated in Figure 35. Wastewater flow through the plant was increased to 1.87 million gallons on this day, while recirculation was reduced to 30,000 gallons. Analysis of the composite sample for effluent phosphorus on this day showed a relatively high concentration of 1.0 mg/l.

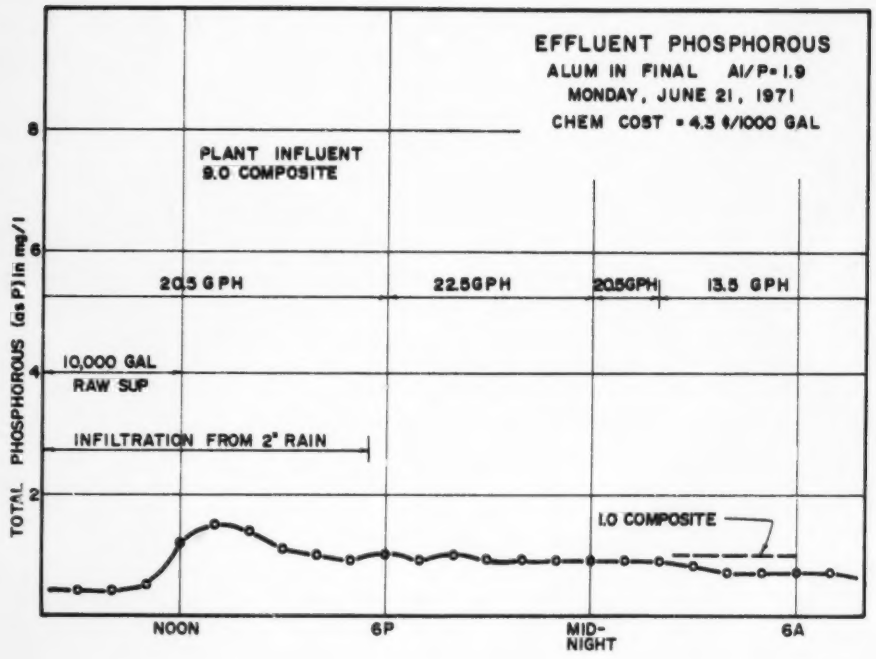

FIGURE 35. PLANT PERFORMANCE PROBLEMS FROM INFILTRATION AND UNTREATED SUPERNATANT.

EFFECT OF LOW WASTEWATER TEMPERATURES ON PERFORMANCE

Table 6 shows some typical low temperature performance data during the extended alum run.

TABLE 6

TYPICAL LOW TEMPERATURE PERFORMANCE

Date	Temperature (°F)		Flow	Phosphorus (mg/l)	
	Raw	Final	(MGD)	Raw	Final
1-23-72	60	56	1.77	11.0	0.5
1-24-72	60	56	1.83	12.8	0.9
1-25-72	60	56	1.73	10.0	0.5
1-30-72	58	54	1.74	11.5	0.5
2-3-72	60	56	1.61	8.6	0.4
2-7-72	64	56	1.78	12.2	0.4

Prior to the dates listed in the table during December 15 - January 18, there were five days when temperature in the final effluent was less than 49° F. These occurred during the holiday season when all but the skeleton operating crew were away from the plant. The chemical feeding operation was shut down for approximately ten days, and it took several days to bring it back into proper operating balance once chemical feed was resumed. This was, unfortunately, precisely the period of time when the effluent water temperatures were the coldest. In looking back over the small amount of data available during this period, no particular observations can be made one way or the other regarding the effect of these coldest wastewater temperatures on plant efficiency.

EFFECT OF PEAK FLOW RATES ON PERFORMANCE

There was very little rainfall during the last three months of the study and peak flows through the plant never exceeded 1.83 MGD. Minimum flows were near 1.35 MGD. Figure 36 illustrates that even within this small range, the rate of flow affected concentration of phosphorus in the effluent.

This rate of flow can be re-expressed in terms of average hydraulic load on the final clarifier as shown in Figure 37. As overflow rates approach 500 gpd/sq ft, effluent phosphorus begins to edge upwards.

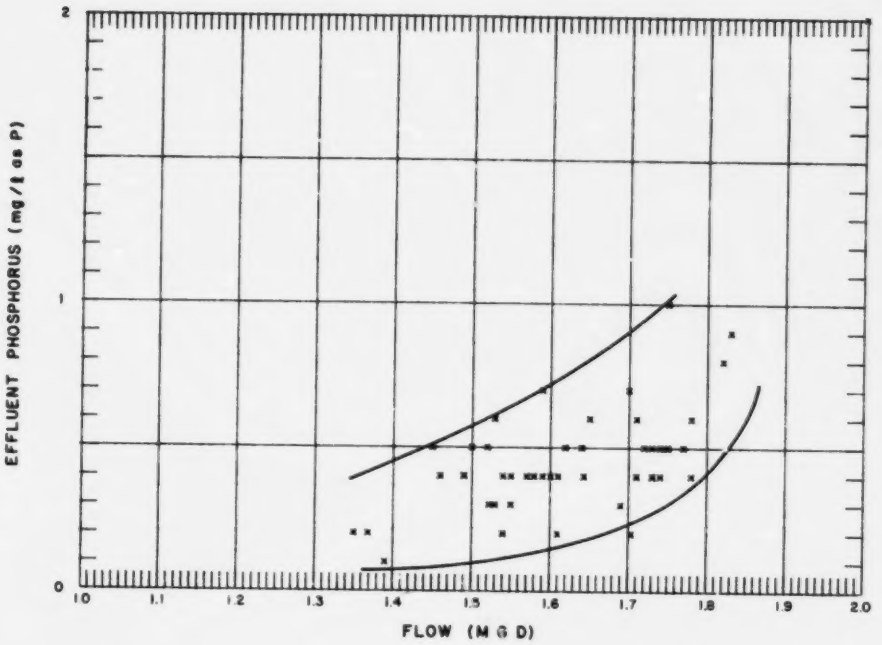

FIGURE 36. EFFECT OF PLANT FLOW ON EFFLUENT PHOSPHORUS.

These overall data were supported by some specific test runs made late in October and in early November, 1971. In these cases, the daytime flow was boosted to a rate of 2.5 MGD (approximately 160% of average daily flow) for periods of four hours at a time. Unless chemical feed rates were increased to compensate for the higher rates of flow, effluent phosphorus composite values increased to 0.8 or 0.9 mg/l for the entire day involved. However, if compensating chemical feed rates were carefully administered, effluent phosphorus concentrations remained at levels of 0.3 or 0.4 mg/l as they had been when the plant was operated at a reasonably constant flow of 1,000 gpm.

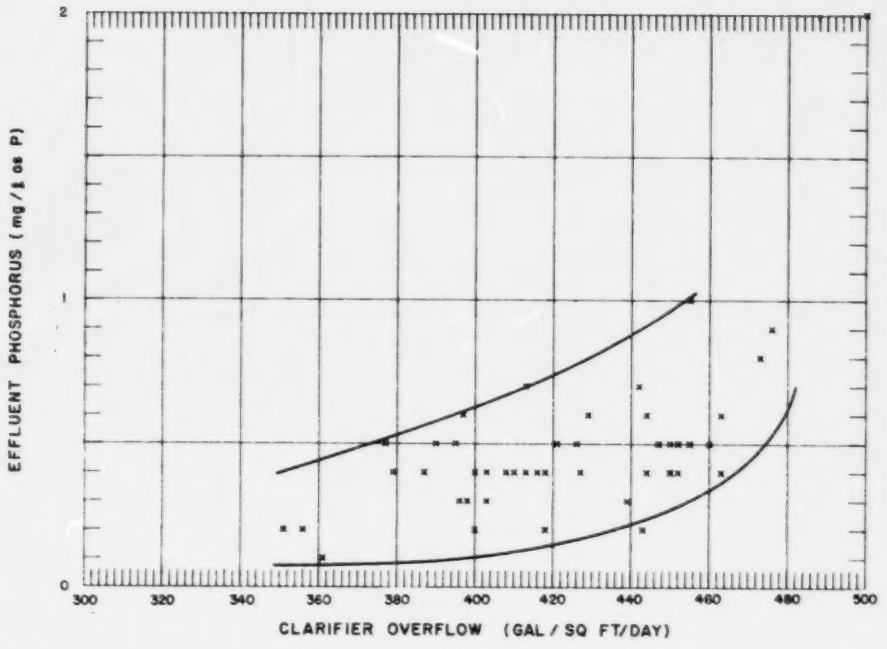

FIGURE 37. RELATION OF EFFLUENT PHOSPHORUS TO FLOW THROUGH THE FINAL CLARIFIER.

EFFECT OF VARYING METAL TO PHOSPHORUS MOLE RATIO ON PERFORMANCE

During the final period of the extended alum run, the plant usually delivered effluent phosphorus concentrations of 0.5 mg/l or less when mole ratios of aluminum to phosphorus of at least 1.5 were utilized (Figure 38). The benefit of utilizing mole ratios much in excess of 1.5 was minimal.

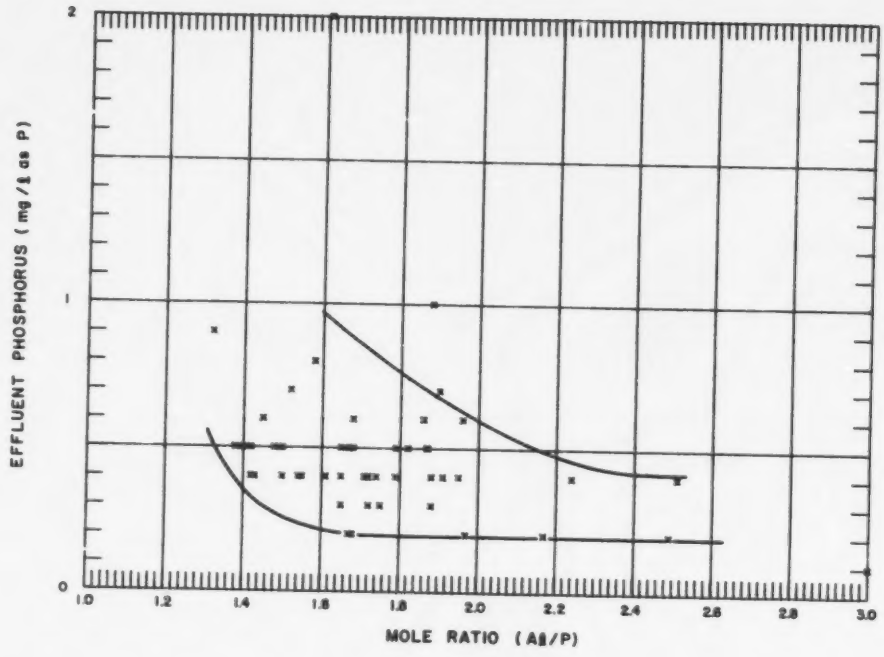

FIGURE 38. RELATIONSHIP OF MOLE RATIO TO EFFLUENT PHOSPHORUS.

CHEMICAL COSTS

The range of costs for the extended run, and the relationship of chemica cost versus effluent phosphorus are summarized in Figure 39. Applying alum at rates which resulted in chemical costs greater than about 5.5 ¢/1,000 gallons of flow yielded little additional phosphorus removal.

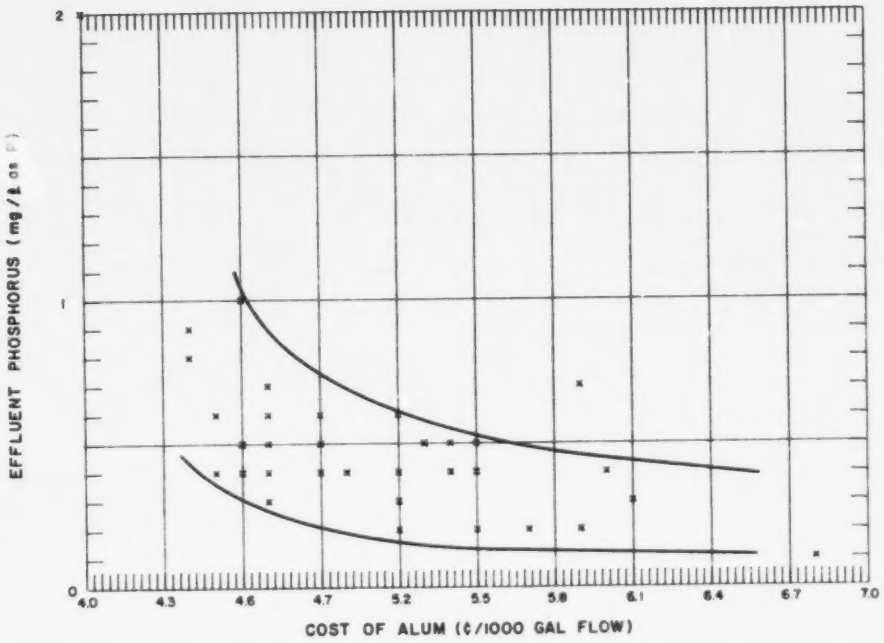

FIGURE 39. COST OF CHEMICAL INJECTED FOR VARIOUS LEVELS OF EFFLUENT PHOSPHORUS.

EFFLUENT SULFATE LEVELS

It was expected that final effluent sulfate concentrations resulting from the aluminum sulfate (alum) injection would be inversely proportional to effluent phosphorus levels. This proved to be the case as shown in Figure 40. Of course, sulfate concentrations themselves also varied according to rate of wastewater flow. On a strict weight basis, about 5 pounds of sulfate were added to plant effluent for every pound of aluminum added during treatment.

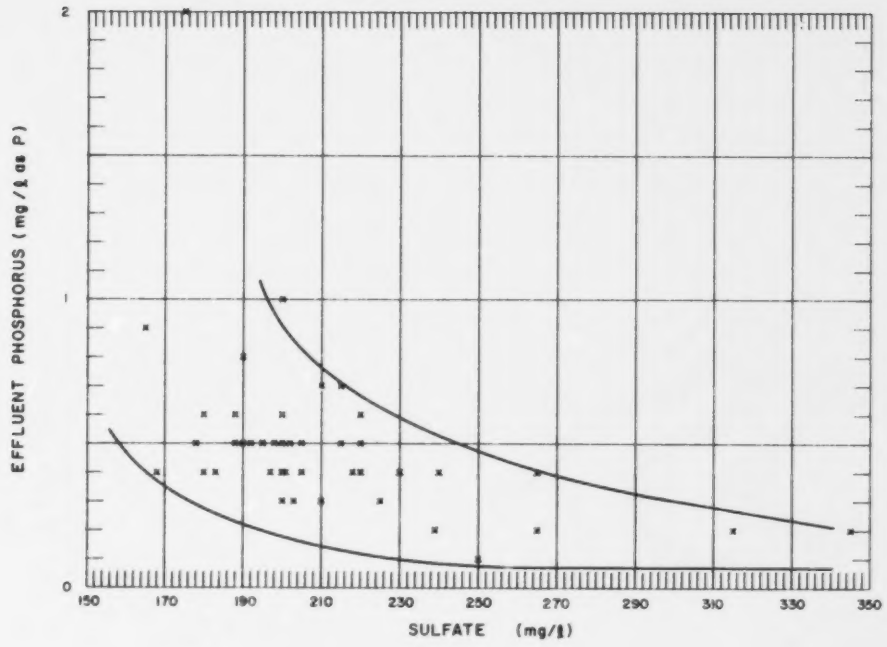

FIGURE 40. RELATIONSHIP OF EFFLUENT SULFATE TO EFFLUENT PHOSPHORUS. (Effluent sulfates increased at low effluent phosphorus levels.)

EFFLUENT ALKALINITY LEVELS

Alkalinity in the plant influent was relatively constant throughout the final test period. Average alkalinity levels have already been shown in Figure 32. Since alkalinity is consumed in the reaction of aluminum sulfate with the wastewater, low levels of effluent alkalinity would correspond to high chemical dosage periods. As expected, then, effluent alkalinity concentration was roughly proportional to effluent phosphorus concentration as shown in Figure 41.

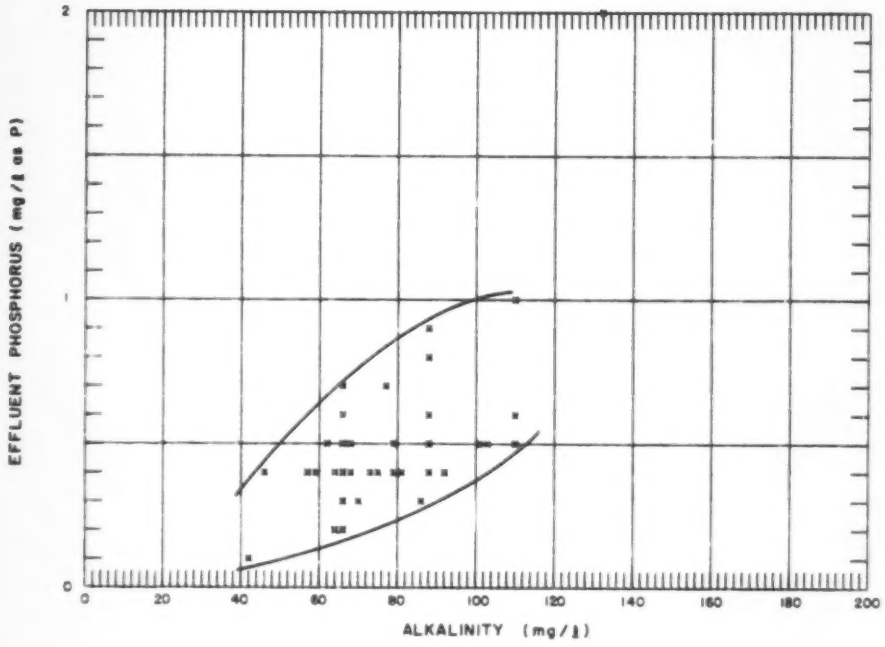

FIGURE 41. RELATIONSHIP OF EFFLUENT ALKALINITY TO EFFLUENT PHOSPHORUS. (Reactions removing phosphorus also reduced alkalinity.)

Plots were also made to try and correlate effluent phosphorus with the following parameters: turbidity, suspended solids, aluminum, and BOD_5. In all these cases, the residual values of the parameters named were so low that the correlation either did not exist or it was not apparent. Correlation with effluent phosphorus could not be shown for effluent pH or temperature either.

SLUDGE PRODUCTION

Digester operation was normal during the extended alum run. Digested sludge production was approximately 950,000 gallons per year, or 1700 gallons per million gallons of wastewater flow. Solids concentration in the digested sludge was about 5 percent yielding an average sludge production on a mass basis of 685 pounds of digested solids per million

gallons of wastewater flow. This compares with typical unit volume and mass sludge production figures of 850 gallons and 410 pounds, respectively, when the plant is operated in a conventional manner without chemical addition.

SECTION IX

PILOT-SCALE FILTRATION AND CARBON ADSORPTION

Facilities for the pilot plant testing described here were shown previously in Figure 8 and discussed in Section IV of this report. The system was capable of handling flow rates between 300 and 1500 gallons per day. Flow control was accurate and easy to maintain at a given rate. Sampling points were numerous and permitted a number of composite samples to be compounded each day. Figure 42 indicates the length of the three separate runs made with the pilot system.

RUN 1	RUN 2	RUN 3
JULY 1 – SEPT 6	SEPT 8 – DEC 21	JAN 2 – MAR 30
1971		1972

FIGURE 42. SCHEDULE OF PILOT TESTS.
(Best data were from high rate trials in Runs 2 and 3.)

Run 1 utilized a throughput rate of 0.26 gallons per minute (375 gpd). This feed rate was dictated by some physical constrictions in the tubing and other facilities that made up the hydraulic pattern. The constricted operation resulted in surface flow rates through the filter and carbon on the order of 2 to 3 gallons per minute per square foot. The data generated during Run 1 seemed reasonable and indicated some trends. However, since the flow rates were unrealistically low, the data had very little significance and is not reported or discussed here.

Runs 2 and 3 were conducted at a flow rate of 0.5 gallons per minute (720 gpd). In both cases, the mode of operating the multi-media granular filter was identical. The continuous rate of flow through that unit was equivalent to 5 gallons per minute per square foot. Direction of flow was vertically downwards through the coal, sand, and garnet.

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The superficial velocity through the carbon columns was the same in Runs 2 and 3, being 6.05 gallons per minute per square foot. However, the direction of flow was upward in Run 2 and downward in Run 3. In terms of treatment efficiency, there was no practical difference between these two modes of operation, so the data for Runs 2 and 3 are combined and presented together in this section. Generalized results are shown in Figure 43.

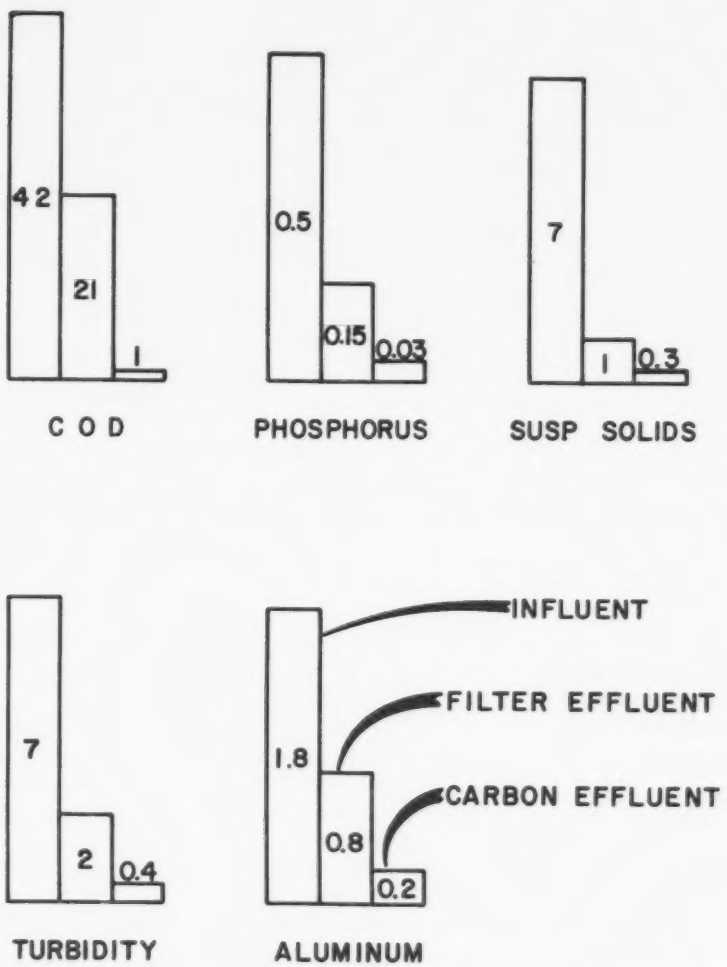

FIGURE 43. PERFORMANCE OF MULTI-MEDIA FILTER AND CARBON COLUMNS. (Influent to this system is effluent from the wastewater treatment plant. All values are in mg/l. The COD figure of one mg/l is a statistical aberation, as discussed in the text.)

The figures shown here have been normalized to represent a central tendency or "reasonable average" of all the data taken during the test period of some 200 days duration. Generally, within each family of data, there were a few extreme values which rendered arithmetic averages unrealistic. On the other hand, most of the families of data were not geometrically normal in the strictest sense either. Therefore, the values shown here have been rationalized and probably represent magnitudes somewhere between geometric and arithmetic means. Effluent COD values reported for the carbon column are statistically valid; they result from a group of "zero" or less-than-discernable values, combined with another group of readings near 5 mg/l. The result is an "average" of one mg/l even though analytical limitations preclude accuracy at that low level.

In very broad terms, filtration through the multi-media unit reduced incoming pollutants to less than half their incoming concentration. Following that, if the carbon system was used with a full 14-foot bed depth, COD was reduced to about 5 percent of its concentration in the filter effluent, and other pollutants were reduced to about 25 percent of levels in the filter effluent.

When operated at a flow rate of 5 gallons per minute per square foot, the filter seemed very stable and reliable in its performance. Backwashing was done on a scheduled basis every 24 hours, and headlosses were on the order of 9 feet by the time backwashing was begun. About 4 percent of the production was used to backwash in the early stages of the pilot plant operation. Later this was reduced to 2 percent and that backwash fraction was retained for the duration of the pilot studies. Attempts to reduce backwash further were not undertaken because 2 percent seemed a reasonable fraction and pilot scale indications of smaller fractions might not be altogether reliable.

Operating four carbon columns in series, each having 3.5 feet of carbon in them, was equivalent to having a single bed 14 feet deep with accurate and accessible sampling at the quarter points. A surface flow rate of 6.05 gallons per minute per square foot is equivalent to a superficial velocity of 0.81 feet per minute. Based on plug flow, this represents an empty bed carbon contact period of slightly over 17 minutes. The carbon used in this study occupied about 50 percent of the volume of columns, however, so actual contact time was on the order of 8 or 9 minutes.

When the direction of flow was upwards in Run 2, carbon in the first bed was fluidized to the extent that there was something like a 10 percent expansion. The three beds following were expanded 5 percent. This upflow rate is probably somewhat greater than used in plant-scale practice today, but there did not seem to be any effect on the operating efficiency in terms of removing pollutants. There were some difficulties during backwashing in keeping carbon in place in the relatively small first column. This appeared to be related to the relatively high solids storage in that small diameter tube.

Specifically, during backwash the carbon there seemed to bridge and hold together. Even with very careful manual washing the carbon tended to migrate upward in plugs until it got very near the top of the lead column. Then the carbon would break up and, in a considerable shower of turbulence, some of the carbon would pass out of the column with the wash water. The small column was not outfitted with a breaker bar, or similar device, which could relieve such problems at plant scale.

Figure 44 illustrates COD levels typically found in wastewater passing through the 14-foot test column. These data indicate the rate of removal was a straight line in the lower part of the curve, and they infer that a zero COD could be gotten by extrapolating beyond the data.

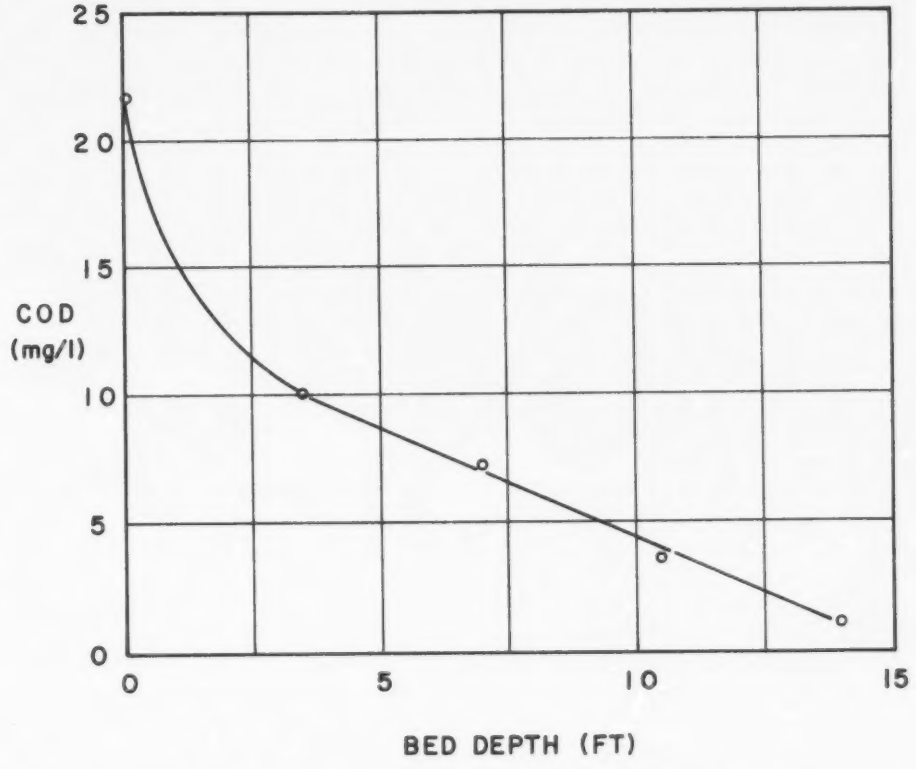

FIGURE 44. COD LEVELS IN WASTEWATER PASSING THROUGH 14-FOOT CARBON COLUMN. (This degree of COD removal was maintained until carbon became exhausted and breakthrough occurred.)

Note that over half the residual COD removal occurred in the first column. Also, visual observations showed nearly all pinpoint alum floc was removed in the first column. This probably contributed to the backwashing problems mentioned previously.

Figure 45 is an analysis of the bed depth versus service time prior to COD breakthrough. A COD level of 10 mg/l was established as breakthrough concentration in this case. That value was sharply apparent (as a functional breakthrough concentration) in the test data.

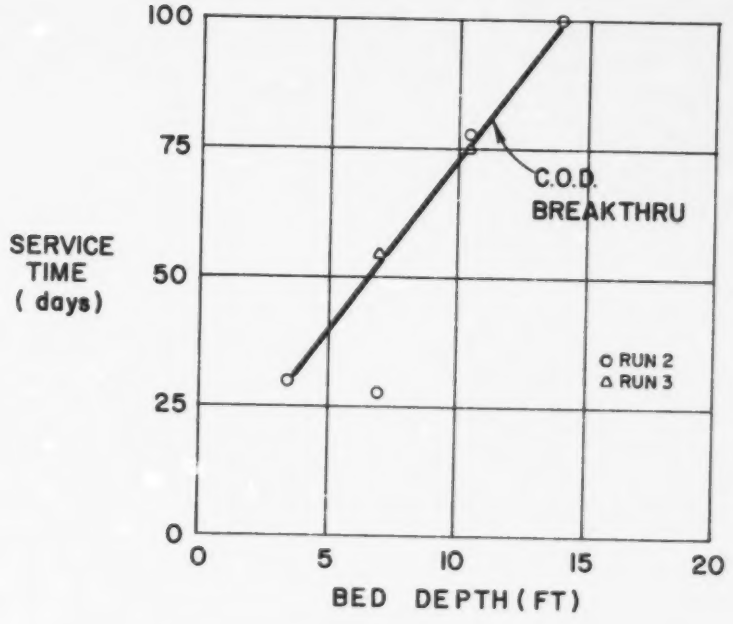

FIGURE 45. SERVICE TIME UNTIL COD BREAKTHROUGH AT VARIOUS DEPTHS OF CARBON.
(Continuous throughput was 6 gpm per sq ft, and exhaustion occurred near loadings of 0.434 lb COD per lb carbon.)

Some of the reported "expansion" mentioned during upflow operation in Run 2 was probably related to the presence of biological growth and alum film on the carbon. This did not occur or was not apparent during

Run 3. To whatever extent bioactivity developed, major dissolved oxygen demands never occurred. Dissolved oxygen into and out of the system remained near 6 mg/l throughout the study.

After the end of Run 3 the pilot facilities were operated for several more months, although data generated during this post-project interval are not analyzed or presented here. It is probably proper to report that the system continued to operate as it had during Runs 2 and 3.

SECTION X

DISCUSSION

Ten subsections are discussed in this section, each addressed to a particular aspect of the investigation reported. These subsections are intended to be reasonably comprehensive if read apart from the main body of the report. To promote this, some key data are either repeated or re-expressed. Persons needing more detailed information should refer to pertinent sections of the main body of the report and Appendix C as well as these discussions.

OVERALL RESULTS

Best results in terms of effluent enhancement occurred when alum was fed just ahead of the final clarifier. This approach proved to be a stable and manageable operation in this plant. When temporary upsets developed, they would generally be preceded by an hour or so of increasing cloudiness in the water in the final clarifier. Thus, operators responding rapidly to a potential upset could adjust their treatment strategy to correct problems before poor quality effluent escaped the plant.

The second best approach, in terms of effluent quality per unit cost, was to split feed alum at an approximate 4:1 ratio, i.e., 80 percent ahead of the final clarifier and 20 percent ahead of the primary clarifiers. There did not seem to be any unique improvement in the effluent using this approach nor were savings in chemical costs indicated. Therefore, split feed seemed a more complicated operation without redeeming benefits in this particular installation.

Feeding metal salt ahead of the primary clarifier did not result in very effective treatment and generally led to sludge digestion problems within a couple of weeks. It is very likely that effluent quality could have been improved if more time and effort had been applied (as it was in feed to the final clarifier); such improvements would have no practical value, however, if they caused digester failure in the plant being studied.

Experiences at this project indicate the best way to establish chemical dosing patterns is to estimate hourly variations in incoming phosphorus load, dose to meet demands, then monitor phosphorus in the plant effluent to see whether refinements are needed in the dosing schedule. Considerable study was required for the first step mentioned. A large number of hourly grab samples were analyzed for phosphorus. These grab samples were taken around the clock for all days of the week. However, once an incoming phosphorus load pattern was established, it was found reasonably

consistent throughout the entire period of this investigation.

An automatic analyzer proved ideal to monitor effluent phosphorus. This apparatus greatly reduced labor required for sampling and analyses. Furthermore, it provided a continuous and reliable record of phosphorus concentrations in treated wastewater. Relatively short-term perturbations were very evident, although they might not necessarily affect 3-hour, 6-hour, 12-hour, etc. composite samples compounded for analysis. These minor perturbations are important if they persist several days, thus indicating a pattern. Such a pattern would indicate feed schedule changes to realize a real improvement in performance.

Changes in chemical dosing rates should generally remain within the established overall daily dosage rate. This daily rate, based on pre-selected mole ratios of metal to phosphorus, should usually provide sufficient metal to accomplish the treatment goals set forth. The really important factor is to take the pre-selected daily ration of metal and feed it to incoming wastewater at rates which allow the most effective utilization of the metal.

In this study, aluminum was preferred over iron, but this choice is reported here without prejudice regarding the potential of the two metals at other locations. As in any wastewater system, Richardson's sewage comprises a highly complex aqueous system. Many of its prime characteristics may never be clearly known, but they probably influence the choice of metal salt. In this case, alum was the better choice. Iron fell short in terms of efficiency and caused color in the effluent (even though aluminum leakage occurred, it was colorless). Sorptive capacity in an activated sludge plant might lead to an opposite course. Probably the key feature is to have the capability of feeding either compound at several points; then, under different circumstances, the better choice can be made.

Leakage of colloidal iron while feeding ferric chloride is certainly not surprising considering the type of plant involved in this study. There was no granular media filtration to polish the final effluent. The secondary treatment system in this plant has far less sorptive capacity than in bio-flocculation inherent with activated sludge. Passing iron-bearing water over the organic film in a trickling filter bed had very little effect, nor was it expected to. The only defense against iron leakage in this plant was gravity settling.

Of course, when iron was fed, residual chlorides increased as did sulfates when liquid alum was being injected. Both of these followed generally stoichemetric levels. Chemical selection will be affected if either extraneous ion is of concern in the receiving water involved.

Aluminum leakage always occurred during both trial and extended alum runs. It was on par with the escaping iron colloids when iron was dosed ahead of the primary clarifiers, except it was not visible. If cases

exist where increased aluminum residuals are to be avoided, then this element would be a key consideration in selection of metals to be fed.

The ultimate solution to colloid leakage lies in recognizing that the metal is probably bound with pollutants such as phosphorus and oxygen consuming compounds. If any of the three require further reduction, then some treatment operation which can remove colloids would be required. Probably the most natural initial consideration would be given to an effluent filtration process of some sort.

Polymers were not given a rigorous trial during this investigation primarily because when alum was dosed at an optimized feed rate, the use of polymers did not improve efficiency or reduce the cost of treatment. As in opting for aluminum, the choice not to use polymers in this study is reported without prejudice to their potential in other situations.

Cold weather operations were never underway long enough to draw any convincing long-term observations in this study. The data that are available indicate low water temperatures neither compromised nor dominated reaction efficiencies and kinetics to the degree that might be expected. Certainly, cold weather effects were less than sometimes seen in water treatment plants. An important difference in considering this historical precedent is that, in the case of treating fresh water supplies, the aqueous system is of a less complex nature than the waters involved in this study. In wastewater treatment, new colloids and natural polyelectrolytes are formed during treatment, and a variety of complex reactions stem from addition of metal salts; these may not occur in water treatment. In summary, although sufficient data for clear definition are lacking, there are strong evidences that wastewater temperatures in the high 40's and low 50's have relatively small effect on precipitation with metal salts.

A far greater effect on operating efficiency lies in control of hydraulics in settling basins. There are clear indications that average daily clarifier surface loadings exceeding 500 gallons per square foot will reduce capture of colloidal phosphorus and other pollutants. Furthermore, instantaneous overflow rates of 1,000 gallons per day per square foot or more caused temporary poor performance which was great enough to adversely affect average daily performance. These features appeared important enough to warrant discussion in the next two subsections.

EQUIPMENT AND FACILITIES

From a physical sense, the clarifiers available in this plant are not particularly efficient. Per present day knowledge of design and operation they have shortcomings as follows: they are relatively shallow (the final clarifier ranges from a 6-foot sidewater depth to 8-foot at the center) and they have some deficiencies in control of inlet velocities (particularly in the case of the primaries). Furthermore, in all instances these clarifiers are outfitted with standard rakes that may

not be the most efficient to handle the increased volume and weight of sludge produced by chemical addition. More efficient tanks would probably handle higher peak liquid and solids loading rates. Very possibly, clarifiers outfitted with tube settlers could have performed markedly better.

Flocculation facilities at this plant were far from sophisticated. The only flocculation energy provided was whatever hydraulic turbulence was available in the flow distribution systems themselves. This meant there was no practical way to control the energy gradient within the flocculation operation. Fortunately, descending hydraulic energy levels are inherent in a system of this type. The basic aims of proper flocculation were served whether or not actual control of the operation was available.

Standard-rate trickling filters comprise about 55 percent of the existing trickling filter facilities in the United States. However, there is no clear indication that different results or new problems would have resulted if high-rate trickling filters had been used at the plant under study.

Sludge digesters of the Imhoff tank type are the simplest used in current practice today. The three parallel digestion tanks at Richardson are in no way better or worse than others of their type around the country. In plants having heated digesters with more effective mixing, it may be possible to accelerate the digestion of combined alum-biological sludges.

Sludge drying beds in this plant are quite marginal in their capacity. Only one square foot per capita is available. Consequently, as discussed in the subsection devoted to sludge handling, a constant struggle was required to stay abreast of increased sludge production and disposal requirements resulting from chemical addition.

CLARIFIER PERFORMANCE

Sludge recirculation was practiced in two important different ways during this study. Both deserve individual attention.

When feeding alum just ahead of the final clarifier, a heavy sludge blanket could be built in that clarifier by careful reduction and control of sludge withdrawal. Since the tank involved here was circular with a centerwell inlet, the solids contact blanket assumed the shape of a doughnut surrounding the centerwell. This blanket of floc extended about one-third the radius toward the peripheral launder. Floc in the doughnut was continuously recirculating, and its motion traced a pattern of turbulence that seemed ideal for low energy flocculation.

The second type of sludge recirculation occurred in the primary clarifiers when alum was being fed just ahead of the final clarifier. The

sludge withdrawn from the bottom of the final was returned to the primary clarifiers where it had a profound and important influence in improving primary settling. For this reason, the results of primary settling are quite atypical, and overall plant performance seems to have been improved by the return of this "spent" sludge which evidently still had considerable usefulness left when admixed with incoming wastewater.

To serve both purposes, it appeared important to keep recirculation rates from the final clarifier low. This technique preserved the solids contact doughnut in the final clarifier and enhanced performance in the primaries by delivering a rich seed sludge there and keeping hydraulic overflow rates to a minimum.

The heavy floc produced by metal addition proved to be excellent tracer material. In fact, for practical studies of basin hydraulics, this floc was the most effective tracer that any of the investigators in this project had ever observed.

One other condition observed in the final clarifier merits discussion. It was apparent that distribution of colloidal COD within that settling tank was directly related to the extent and concentration of floc particles. A COD profile showed this pattern and indicated that if a large skirt were added outside the existing centerwell and about halfway to the outer wall, that considerable additional reliability would result in retention and capture of COD and suspended solids. This would, in effect, enclose the low energy flocculation process.

SLUDGE PRODUCTION, DIGESTION, AND DRYING

Slightly less than one percent of the total plant flow of wastewater was withdrawn into the sludge handling system when chemicals were added as a part of treatment. This amounted on a yearly basis to between 900,000 and 1,000,000 gallons of digested sludge (about 2,600 gallons per day) and approximately 3,500,000 to 5,000,000 gallons of digester supernatant (about 10,000 to 14,000 gallons per day). The digested sludge was withdrawn to sand beds for drying and the supernatant recycled (either with or without separate alum treatment) to the plant's influent wet well.

As described earlier, the three parallel digesters are not heated and do not employ mixing in the usual sense of the word. Stirring is provided in each digester by truss members attached to an extension of the vertical shaft driving the clarifier mechanism above. These truss arms rotate at three revolutions per hour and constitute all the mixing provided in the digesters.

On a population basis, the volume in these digesters equates to approximately 3 to 3.5 cubic feet per capita. Considering the amount of sludge digested and withdrawn (but excluding supernatant), displacement time through the digesters for solids averaged between 5 and 6 months during

the project. This long residence time probably explains why, when low wintertime temperatures developed, the digesters were able to either continue effective digestion at a reduced pace or perhaps store organic matter until warmer temperatures stimulated bacteria to accelerate their activities.

Cold weather dropped temperatures in the digesters to as low as 65° F, while in the summer they rose to nearly 85° F. In the same period, maximum and minimum values of pH ranged between 6.5 and 7.4. Digested sludge consistency did not vary greatly, however, remaining on the order of 5 to 6 percent throughout the year when alum was being administered. The volatile fraction of digested sludge was consistently near 45 percent.

Prior to chemical addition, annual sludge production averaged about half that experienced during chemical precipitation. Total production of digested sludge was in the range of 450,000 to 500,000 gallons per year (about 1,300 gallons per day). Nonchemical sludge had the tendency to be slightly more concentrated, within the general range of 6 to 7 percent solids by weight.

Generally speaking, digested sludge during iron addition was somewhat heavier than during alum addition. There are no irrefutable records to support this because iron was only added for the better part of three months while at least twice that long was required to establish a clear pattern of the effects of a particular chemical.

As anticipated, both aluminum and iron eventually concentrated in the sludge during their respective dosing periods. Final concentrations of the metals in the digested sludge were on the order of 3 to 4 percent by weight. Phosphorus also concentrated in the digested sludge and reached levels on the order of one percent by weight. There was never any indication that phosphorus resolublized in the supernatant, although it was present in the range of 100 mg/l as colloidal solids.

At one square foot of space per person served, drying bed capacity at this facility was critically short. This drying capacity was considered standard design practice at the time the plant was built, but subsequent experience has proven there is very little, if any, reserve in such a drying bed system. During the course of operating the treatment plant prior to chemical addition, there were occasional periods when drying capacity was marginal. With chemical precipitation, the volume of sludge generated doubled, so certainly the logistics of getting sludge on and off the beds became more critical and shortage of drying space became a greater problem. Consideration was given during the course of the experiments to digging an emergency lagoon; however, as it turned out the operating crew was able to handle sludge just fast enough to avoid this emergency procedure.

On two brief occasions, weather conditions prevented full utilization of available drying beds, causing sludge to accumulate in the digesters until finally it backed up through the sludge hole in the floor of the primary

clarifiers. These conditions resulted in discoloration of primary effluent and severe deterioration of the quality of that water. Both of these instances were short in duration and had little or no effect on overall performance. They did indicate what could happen if conditions causing them were not corrected.

Although the volume of digested sludge doubled when chemicals were added, no net increase in drying bed capacity was required if the weather cooperated. This stemmed from the fast drying nature of the combined chemical-biological sludge. Conventional digested sludge was, over a long time average, dried and stripped from the beds in a period of 20 to 22 days, weather permitting. Under the same circumstances, the combined chemical-biological sludge could be dried and removed on 8 to 10 day cycles. Clearly, the additional volume of sludge could be handled provided rainy weather was not encountered and assuming additional manpower was always available.

SUPERNATANT TREATMENT

By the time the study period was completed, the operating staff at this treatment plant had accumulated over five years' experience in treatment of supernatant returned from anaerobic digesters. As described earlier, the original system was a relatively crude batch-type approach and chemical feed was not optimized in those early years. This subsection offers comments on how the overall system progressed and what the best arrangement seemed finally to be.

The volume of supernatant at this treatment plant could and does vary considerably from week to week. It is generally near one-half to one percent of total plant flow. This is probably more supernatant than is drawn at most biological treatment plants, but drawing such volumes has historically helped overall treatment efficiency at Richardson. Supernatant is usually drawn during parts of either two or three days per week. On these days, about 10,000 gallons of liquor is decanted from each of the three digesters, totaling 30,000 gallons or approximately two percent of plant flow that day. If weather or other operating conditions dictate, supernatant is drawn only twice per week or perhaps just once. Also, operators draw more than 10,000 gallons from a given digester if on-site sampling and observation indicate a larger draw is called for. For these reasons, then, supernatant withdrawn per week can range from as little as 30,000 gallons to as much as 100,000 gallons or more.

On a typical day when supernatant is being returned at the rate of 30,000 gallons, it will contain colloidal phosphorus of 100 mg/l. This would cause an obvious increase in total phosphorus in the raw wastewater if supernatant were not treated. The increase would be on the order of 2 mg/l, representing something like a 15% surcharge in phosphorus inflow concentrations. As already shown in Figure 34, untreated supernatant leads to higher phosphorus values in the plant effluent. Suspended

solids and other pollutant concentrations increase too, and generally in similar proportions.

On the other hand, when supernatant was treated (either continuously or on a batch basis), there was never any problem in overall plant operation because of its return to the raw inflow. Typical before and after pollutant concentrations in treated supernatant were shown previously in Figure 11. To treat supernatant, aluminum was dosed at an average M/P mole ratio of 1.8/1.0. This comment infers operators made an estimate of phosphorus concentration in supernatant each time which was not so; they added to meet an assumed demand. That estimate would not be confirmed until the next day. To be more specific, operators batch treating supernatant would add 1.5 gallons of liquid alum per 500-gallon tank. In earlier trials, they had been adding 3 or 3.5 gallons, and it took a while before the operators recognized they could cut their alum dose and still obtain essentially the same results.

At the higher dosage just mentioned, supernatant treatment cost 40¢ to 50¢ per thousand gallons of liquor. Once the reduced dosage was confirmed, the unit cost dropped to about 23¢. The same chemical feed rate was maintained when the supernatant treatment system was converted to a 32 gpm continuous operation.

Ultimately, chemical costs were more related to the amount of supernatant drawn within a given week than to any other factor. If 50,000 gallons were drawn, the average cost of treating supernatant would be 0.1¢ per thousand gallons of wastewater treated in the main plant; if 100,000 gallons of liquor were drawn in a given week, the cost would double to 0.2¢ per thousand gallons of wastewater handled in the main plant. In either case, the cost was considered modest and the improved plant performance well worth the time and effort.

PILOT ADSORPTION AND FILTRATION

The primary goal of this project was to evaluate plant-scale chemical addition as a means of upgrading overall plant performance. Pilot-scale carbon adsorption and multi-media filtration studies were ancillary operations to the main effort. They were undertaken to see what improved performance could be expected and what size units would be required if these processes were added to the present system.

Without any question, it seemed clear that filtration was a reliable and reasonable method to improve capture of colloidal and other suspended solids in the treatment plant effluent. For example, this solids capture system would have been an excellent backup during the periods of time that oxidized iron colloids were escaping with the plant effluent and causing a highly undesirable red color. (This conclusion does not infer that the pilot units were being operated during the iron trial. They were not. But filter performance on finely divided alum solids indicates iron particles would have been caught.)

Tertiary pilot filtration data show suspended solids were reduced during main-plant alum treatment from a level of 7 mg/l to 1 or 2 mg/l as a consistent matter of course. By allowing head losses to build to eight or ten feet prior to backwashing, 24-hour filter runs were routinely achieved. Filter rates of 5 gallons per minute per square foot were used on a continual basis. The pilot filter consistently reduced COD values by half and phosphorus levels to below 0.25 mg/l.

The study unearthed no new information on theoretical or applied filtration technology. Rather, the test filter was run for extended periods of time until performance data established design parameters to a high degree of confidence.

Generally, these same comments can be made about the carbon absorption system. The four columns were run in series for three month periods. Their performance definitely indicated that full-sized carbon adsorption units following tertiary filters could be expected to reduce pollutants to near trace levels.

The proposed loading rates to achieve this type of results in full-scale operation would be 0.43 pounds COD per pound of activated carbon. In units 14 feet deep, this would entail a flow rate of 6 gpm per sq ft for a period of 60 to 90 days. It made very little difference in the pilot studies whether carbon columns were operated downflow or upflow. Either orientation would probably serve in plant-scale units.

In looking at the entire pilot system, there is clearly a range of effluent polishing available. The multi-media filter alone can produce water of a defined quality which will meet the water quality requirements of many communities. An important side benefit with filtration is the backup or safeguard function it provides to an existing treatment plant.

If still better effluent is required, carbon can be used as an adjunct to filtration. Data show that, within the carbon adsorption process, a range of effluent quality is possible. For instance, the bed depth could be chosen to suit different needs, or some value besides 10 mg/l of COD might be used as a breakthrough concentration.

In summary, the pilot studies generated valuable data and experience which can be utilized in upgrading the Richardson Treatment Plant as future requirements dictate.

DRAINAGE FROM SAND DRYING BEDS

In Richardson, for every ten gallons of digested sludge put on drying beds, about one gallon reappears eventually as underflow and is returned to the head of the plant. Of this ten percent underflow return, well over three-fourths of that volume will come through in the first 48 hours. This return factor may or may not be typical of experience at other treat-

ment sites, but whatever the return fraction, some observations on the nature and treatment of that underflow may have broad application.

Over a period of years the local staff observed that if certain precautions were taken, sand bed underflow would be relatively clear and pure. If these precautions were ignored that liquor would be dirty, strong, and fully as undesirable as its close kin, digester supernatant.

Probably the strongest single conviction which developed out of this long period of operation and observation is that the sand layer (in this case the upper six or seven inches of the drying bed itself) should never be allowed to get too thin to do its job. Each time a load of sludge is stripped from the beds, as much as 1/4 inch of sand can be taken off with the sludge. This attrition is neither unusual nor controllable; it is a fact of life in the operation of sand drying beds and ought to be recognized as such. Therefore, if the beds are to continue to perform properly, the sand should be replaced at frequent intervals. The replacement sand should be of medium to coarse grain, rather than a very fine beach or field sand which tends to plug and impede percolation down into the underdrainage system.

If the sand layer is properly maintained, it should provide good filtration and surface biological action. It should yield a clear underflow water with qualities near those expected from a primary or possibly a secondary treatment plant.

The preceding remarks dealt with the quality of underdrainage water. An equally important factor is the rate of dewatering. Observations at this plant indicate the sand layer needs attention between each loading. This attention consists of fluffing the sand with a rake or a small power driven implement. Then the scarified surface should be allowed to dry for a day or so before receiving another load of digested sludge. Leaving the bed open and fallow is probably against human nature; the natural tendency is to draw a new load of sludge onto the bed quickly so that the drying cycle can begin anew. However, at Richardson, if the sand is fluffed and allowed to dry, it seems to have more adsorptive capacity, a higher permeability, and a rejuvenated capacity for purifying the underflow water.

THINGS THAT DID NOT WORK

No long-term research and development effort can be completed without making a variety of mistakes. The mistakes made on this project are explained in sufficient detail in this subsection that others might benefit.

The final clarifier sludge recirculation sampler shown in Figure 7 was mechanically reliable. It was easy to adjust and simple to maintain. It cost very little. As a mechanism, it was a success. Unfortunately, the

flow of water it sampled was in no way representative, so resulting sample portions were not only nonrepresentative, they were unrealistic and misleading. False samples were taken for a period of months before the situation was recognized. The problem lay in the fact that, when using 20-minute pulse blowdowns from the bottom of the final clarifier, the rate of flow and character of the fluid was highly variable over the 25-second blowdown cycle. Different schemes were tried, without success, to obtain representative samples of this stream. It was finally concluded the only way to get a good representative recirculation sample would be to combine all the 90,000 gallons per day in one tank, stir it, and then take the sample from that total mixed volume. This was, of course, unrealistic and a satisfactory recirculation sample was never gotten, making it impossible to reliably calculate the impact of the recirculation flow on raw wastewater characteristics.

Very early in the investigation an attempt was made to measure flow through a trickling filter by gaging water head in the center column. This also did not work. The center column was tapped and a transparent calibrated water gage mounted on the outside. Water level could be determined by an operator standing at the edge of the filter, so this was not the problem. Rather, practical failure resulted from the fact that the water level fluctuated continuously over an approximate three-inch range, and that range seemed to fluctuate within a larger and less frequent harmonic. Furthermore, the head-discharge curve for the trickling filter distributor (which is, in effect, an orifice system) was highly sensitive to the variations in head imposed. The whole approach represented no more than a gross evaluation of the amount of water going through the distributor.

Standard one-inch water meters were installed to measure underdrainage flow from the sand drying beds. This seemed like a very obvious and practical idea as the flow throughout the many years it has been sampled at Richardson had always appeared to be sufficiently clear and clean to run through conventional water meters without problems. It was not recognized that the small sump pumps used to drive underdrainage through the meters would pick up loose fine sand in the bottom of the collection sump. The pumps hurled these abrasive particles into the water meters causing severe wear and other maintenance problems. (Physical limitations at this site made it impractical to have deep sumps which would prevent sand particles from being picked up by the pumps.) The water meters lasted long enough to obtain good flow readings for typical sludge bed drainage periods. When they failed, measurement of underdrainage flows was terminated.

The final clarifier in this treatment plant also serves as the chlorine contact chamber. Under normal circumstances, there were no problems in collecting a sample of effluent partway through the clarifier and pumping it to the automatic chlorine analyzer. However, when alum was being added, the floc generated in the final clarifier necessitated filtering the sample through a traveling paper filter or some similar mechanism

prior to injection into the analyzer. Failure to filter this sample flow caused the instrument to clog.

For the first few months of operation, a dissolved oxygen analyzer was stationed in the plant effluent channel. A continuous recorder was attached and an excellent strip chart record of effluent dissolved oxygen was produced. Unfortunately, colloidal aluminum particles mentioned previously also affected the sensing section of this apparatus. In fact, it became very difficult to keep the sensing probe in operable condition for more than a few hours. Fortunately, it was also unnecessary to have a continuous record of dissolved oxygen concentrations. Grab samples at all hours showed oxygen tensions were continuously at the level of 5 to 7 mg/l. Entering an "average" value for oxygen concentration for the day based on these grab samples was an easy and justifiable procedure.

An unexpected and serious problem developed when alum was being fed to untreated wastewater entering the plant. After floc developed in the main wet well, wastewater was pumped through a pipeline to the primary clarifiers. In this pipeline, there was a venturi meter which included a differential pressure cell utilizing mercury columns. Somehow, particles of alum migrated to and congregated in the mercury chamber, clogging the tubing to the transmitters. This problem which also plagued the final clarifier recirculation meter throughout the project was never satisfactorily resolved.

Two mistakes were made in the design and provision of polymer addition facilities. The first was installation of a manual dispensing system. At about the time this project began, and certainly in the two or three subsequent years, there have been several automatic polymer dispensers offered for this type of service. Several of these appear to be highly reliable and reasonable in cost and would have been a considerable improvement. Another miscalculation was the decision to install the polymer feed system without shelter. Designers and operators alike agreed that discomforts of wet or windy weather during polymer mixing made the cost of simple shelter very reasonable.

UNANSWERED QUESTIONS

From time to time, addition of alum ahead of the final clarifier caused a luxuriant foam in the final effluent. The foam was present on the water traveling around the launders of the clarifier and was more apparent in the plant effluent ditch where an 8-foot head loss was expended in intense turbulence. The foam was generally white and contained fairly high concentrations of colloidal pollutants including phosphorus compounds. The foam seemed to be intensified by chlorination. Curiously, this foaming tendency was not persistent; it probably occurred during approximately 20 percent of the project. Some consideration was given to making use of this foaming tendency in a foam separation process to be pilot tested on site. Time and funds did not permit this prospect to be evaluated, however.

Without being able to present clear correlation, it seemed that chlorination had a deleterious effect on phosphorus removal by alum addition. Within broadest limits, the more chlorine added, the more alum was required to maintain effluent phosphorus concentrations at a consistent level.

The techniques of sampling, or more probably the techniques of analyzing, prevented a reasonable mass balance of nitrogen in the system during the study. Typical ammonia nitrogen values seemed reasonable, some 25 mg/l entering the plant with half that much in the final effluent. Nitrite nitrogen was scarcely ever present in significant amounts. Nitrate nitrogen concentrations in the final effluent were usually low and appeared reasonable. When all these were added together, however, they missed balancing with Kjeldahl nitrogen by a considerable amount. Since nitrogen considerations were not part of this study, the matter was never checked out in detail.

COSTS

The greatest single cost factor in this project was the cost of chemicals. To this must be added some allowance for increased sludge handling and disposal costs. Capital equipment costs were both minor and singular to this particular situation; other plants should apply equipment costs described here to their own situations with considerable caution.

The average cost for chemicals during the final extended alum run was on the order of 5.1¢ per thousand gallons ($51 per million gallons). This figure is based on buying alum at a rate which placed the cost of trivalent aluminum, or Al (III), at 25¢ per pound plus some 12¢ per pound to transport the liquid a distance of 300 miles. These operating-oriented figures were derived from the following costs expressed in the commercial world of liquid alum sales: the base cost of 17 percent aluminum oxide was $43 per ton and freight in minimum truckload lots of 42,000 pounds was 51¢ per hundredweight. These figures also translated into another very usable form of 17.3¢ per gallon of liquid alum. Each gallon of alum weighed some 11.1 pounds of which 0.485 pounds was trivalent aluminum.

There may be value in moving towards the more universal expression of chemical cost per pound of phosphorus removed. In this case, the cost applies to reduction of phosphorus from 11.4 to 0.5 mg/l. With a removal of 10.9 mg/l, a plant flow of 1.55 MGD, and an Al/P mole ratio of 1.6, figures out to 36 cents per pound of phosphorus removed.

Additional operating costs included relatively minor items such as $200 or $300 per year for electricity, about $250 per year for miscellaneous replacement parts for pumps and other working parts, and some allowance for paint, grease, and maintenance manpower.

No additional operators were required to run the plant when chemical addition was brought into the treatment scheme. The laboratory was already staffed to support conventional treatment and did not need any additional analysts to support chemical treatment. The additional lab staff utilized were required only for the purpose of supporting the project and would not be necessary on a strict operational basis.

Identification of capital cost for chemical addition equipment becomes confusing in this case if the reader tries to separate the equipment needed for chemical addition at a typical plant from the actual equipment supplied to support this project. For example, a $3,000 zetameter and automatic pH and dissolved oxygen monitors were purchased strictly for research purposes; they would not be needed in a plant upgraded to permit chemical addition. Some other improvements were made because it was believed they would improve overall plant operation; an example of this is the addition of a new $7,000 automatic chlorinator when the original smaller manual unit was still capable of doing a fairly good job of disinfection. The $4,000 spent on magnetic meters to monitor raw and treated supernatant flow also would probably not be necessary in a typical operating plant. For this project, the capitalized costs (10 years at an interest rate of 5.5 percent totalled something less than 2¢/1,000 gallons treated.

In summary, total cost for chemical addition at Richardson amounted to 7¢ to 8¢/1,000 gallons treated, of which something just over 5¢/1,000 gallons was consumed in chemicals.

SECTION XI

ACKNOWLEDGMENTS

Mr. Derrington, Director of this project, was Water Superintendent at the City of Richardson, Texas; he is presently Operations Manager for Wastewater Treatment at the North Texas Municipal Water District, Wylie, Texas.

Mr. Stevens, Project Manager, is Assistant Director of Utilities at the City of Richardson.

Mr. Laughlin, Associate Director, is a partner in the consulting engineering firm of Shimek-Roming-Jacobs & Finklea, in Dallas, Texas.

A number of people from the United States Environmental Protection Agency made notable contributions to this project:

Mr. Richard Brenner, National Environmental Research Center, Cincinnati, Ohio, was Project Officer for the duration of the study; he probably devoted more time to this project than any other person besides those directly involved in its prosecution.

Mr. Edwin Barth, National Environmental Research Center, Cincinnati, Ohio, was active in the inception of the project and encouraged organization and pursuit of work reported here.

Mr. Patrick Tobin, Office of Research and Monitoring, Washington, D.C. gave administrative support to the project as it drew towards a conclusion.

Mr. Larry Kamphake, National Environmental Research Center, Cincinnati, Ohio, set up the automatic phosphorus analyzer and provided considerable assistance in refining other analytical techniques used by the control laboratory.

Dr. William Duffer, Robert S. Kerr Water Research Center, Ada, Oklahoma, and other members of his staff helped instruct project personnel in special analytical techniques and in methods of laboratory quality control.

Mr. Robert Crowe, Technology Transfer, Washington, D. C., and members of his staff helped disseminate information generated and brought an influx of suggestions from related researchers during the course of this study.

Mr. George Putnicki and Mr. Robert Hiller, Region VI, Dallas, Texas and other members of the Regional Staff provided local support and encouragement.

Three individuals were engaged as expert consultants and, from time to time, met with the project staff to review progress and offer suggestions:

Dr. C. H. Connell, Consultant, Bertron, Texas; formerly Professor of Preventive Medicine, University of Texas Medical Branch, Galveston, Texas.

Mr. I. W. Santry, I. W. Santry & Associates, Dallas, Texas.

Mr. C. L. Shimek, Shimek-Roming-Jacobs & Finklea, Dallas, Texas.

Pilot facilities for granular media filtration and carbon column adsorption were provided through general coordination of Neptune MicroFloc, Inc., represented by Mr. Howard Shireman, Dallas, Texas. Carbon columns and the granular carbon were supplied to the project by ICA America, Inc.; their Mr. Paul Stubbe and Mr. James Black provided advice and on-site assistance in getting these units in service and interpreting the data generated. Mr. Shireman provided the same type of service for the support hardware facilities as well as for granular media filtration equipment.

Electronic data processing support was supplied primarily through Mr. Donald Wilson of Compuroute, Garland, Texas. Mr. Wilson set up the original statistical programs and other elements of hardware including printout formats and interface coordination with microfiche equipment. During final stages of the project, Mr. David G. MacKenzie, Teledyne Geotech, Garland, Texas, provided active support. Mr. MacKenzie refined some of the statistical software, advanced and refined microfiche translation operations, and generated a variety of computer plots such as probability and scatter diagrams. He is the author of the flow chart shown in the appendix dealing with data processing.

Finally, the Mayor and City Council of the City of Richardson gave their continued strong support and encouragement during the project. A number of departments within the City Staff were involved in the project, including the office of the City Manager, general administrative personnel, and a variety of people in the Water Department such as operators, maintenance specialists, laboratory personnel, and administrators. This entire group provided uncounted hours of dedicated support.

SECTION XII

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SECTION XIII

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APPENDIX A

LABORATORY OPERATIONS AND FACILITIES

There were thirteen sampling points in the treatment plant, and up to twenty-three analyses might be run on composite samples taken at any one of them. Figure 1 summarizes the stations and analyses involved. Approximately 140 items of data were reported each sample day.

A staff of three analysts worked five days per week, usually Monday through Friday. The samples they analyzed were collected Sunday through Thursday. Occasionally, they worked on weekends to analyze samples collected Friday and Saturday. A fourth analyst, working about 30 hours a week, helped handle the heavy laboratory load generated by the demonstration project. A staff of this size would not have been required to support the treatment plant if the only aim were plant operation rather than investigation; one analyst would be sufficient for a plant of this size and type under normal operating conditions.

Some of the equipment used in this project might be of interest to others. A Technicon Auto-Analyzer was used to determine total phosphorus in the plant effluent. An optimized apparatus was under development by the Technicon Company at the time the necessary individual components were assembled and put into service in this study on a trial basis by EPA. Since then, the company has made the equipment available on a commercial basis. A Hach Model 2100 A Turbidimeter was obtained for the last nine months of the study; this instrument was most helpful in providing accurate measurement of final and intermediate effluent turbidity. Two Bausch & Lomb Spectronic 20's of the solid state type were used in the laboratory; one was set up for and dedicated to phosphorus analyses. The other Spectronic 20 was used for a wide variety of colorimetric analyses. An American Instrument microstill was used for determination of total Kjeldahl nitrogen. All of this equipment served the project well.

Other equipment made available for the laboratory included a Zetameter (not used to its fullest potential in this particular project as discussed in Section X) and a Taulman Turbitrol brand jar test apparatus (whose performance was generally satisfactory).

Laboratory procedures were performed generally in conformance with the classic analyses described in standard references (8) (9). At the time the project began, some of the analyses in these recent references were in a tentative form. Subsequently, however, they have been refined as reported in the references.

Other treatment plants considering chemical addition to enhance plant performance need not undertake all of the analyses shown in Figure 1. For operating control, those required would include all the analyses

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	RAW	PRIM EFF	FILT EFF	FINAL EFF	RECIRC	SLUDGE 1	SLUDGE 2	SLUDGE 3	RAW SUP 1	RAW SUP 2	RAW SUP 3	TREAT SUP	BED DRAIN	
FLOW	●				●	●	●	●	●	●	●	●	●	
TOT SOL	●	●	●	●	●	●	●	●	●	●	●	●	●	
TOT VOL SOL	●	●	●	●	●	●	●	●	●	●	●	●	●	
SUS SOL	●	●	●	●	●				●	●	●	●	●	
SUS VOL SOL	●	●	●	●	●				●	●	●	●	●	
SET SOL	●	●	●	●										
BOD	●	●		●					●	●	●	●		
DO	●			●										
COD	●	●	●	●	●				●	●	●	●	●	
PHOS	●	●		●	●	●	●	●	●	●	●	●	●	
TKN	●	●		●	●	●	●	●	●	●	●	●	●	
NH3	●	●		●		●	●	●	●	●	●	●	●	
NO2				●										
NO3	●			●										
ALK	●	●		●		●	●	●	●	●	●	●	●	
FE	●	●		●	●	●	●	●	●	●	●	●	●	
AL	●	●		●	●	●	●	●	●	●	●	●	●	
S	●					●	●	●	●	●	●	●		
SO4	●	●	●	●		●	●	●	●	●	●	●	●	
CL	●	●		●										
PH	●	●	●	●		●	●	●	●	●	●	●	●	
TEMP	●	●	●	●		●	●	●	●	●	●	●	●	
TURB	●	●		●										
COLI	●			●										
FECAL	●			●										

FIGURE 1 - APPENDIX A. ANALYSES PERFORMED ON COMPOSITE SAMPLES. (Thirteen sample stations and up to 25 analyses per station were involved. About 140 items of data were generated on a typical day.)

done previously (in a conventional operation) plus those related to phosphorus and the metal salt being added. Analyses for alkalinity would be required if terminal concentration, after treatment, was 50 mg/l or less.

A concerted effort was made during this project to insure reliable data reporting. Towards this end, a laboratory quality control program was established and maintained throughout the project. Many laboratories run duplicate samples to verify precision and standard solutions to check the accuracy of analyses. In this case, the results of these procedures were recorded and handled statistically to verify whether or not the efforts of all the analysts and the reliability of the apparatus were acceptable. This technique (10) indicated data reported here are valid.

Bacterial tests included both total and fecal coliform analyses. These tests were the only bacteriological work undertaken during the course of this study. A special room was dedicated to this work. A full time bacteriologist was not available, however, and one of the regular analysts performed coliform analyses one or two times a week. Nearly all of these tests were performed on treated effluent in an attempt to differentiate the degree of coliform removal afforded by baseline operation and routine chlorination versus addition of chemicals with and without chlorination.

The jar test apparatus was used heavily at the beginning of the trial runs with iron and aluminum. The apparatus was also used when various polymers were under preliminary consideration. However, proof testing of polymers was done on a plant-scale basis and did not require extensive jar testing. Overall, the jar test apparatus was used only during 5 or 10 percent of the project.

APPENDIX B

DATA PROCESSING

It is no overstatement to say that generation of 140 items of data per day can soon lead to problems in data processing. Considerable time and effort were devoted during early states of this project to devise a reasonable and effective way to handle data; i.e., to accumulate it in an accessible form and retrieve and manipulate it in a meaningful way. Some of the key elements of the data processing program are reported here for the interest of others involved in similar operations.

A fundamental decision was made quite early: data generated in the laboratory should be recorded only once. That record, with related calculations, was to be entered on bench sheets used by the analysts themselves. A typical bench sheet (for ammonia nitrogen in this case) is shown in Figure 1. The analyst is required to fill in the date and then the calculations for derivation of ammonia concentrations at any of 11 sampling stations. Stations where a particular test was not done were omitted as evidenced by blanks for trickling filter effluent and recirculation flow in the example being used. After the analyst had prepared the samples according to the particular procedure involved, the absorbance (for example, 425 millimicrons for ammonia) was measured and recorded. Then all calculations for these samples could be carried forward and recorded under "Results". The "Results" column includes an obligatory decimal point. Values derived there are rounded off and recorded finally under the column entitled "Computer".

At the beginning of a given calendar day, all of the analyses were assembled into a complete set of blank bench sheets. The packet would be split up and sheets given to those who would perform particular tests. When the analyses were completed, the packet was re-assembled and represented the entire laboratory effort for that particular day.

No manual transcription of the original laboratory results into daily, weekly, or monthly summaries was necessary during course of the project. Rather, all laboratory data were transcribed from bench sheets directly onto computer cards. The column numbers for these cards are shown in Figure 1 and those familiar with electronic data processing will quickly appreciate the intent and extent of this operation. Every month or so, the packets of bench sheets would be card punched and carded data translated onto magnetic tape for processing with any of several programs.

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PARAMETER 14 NH3

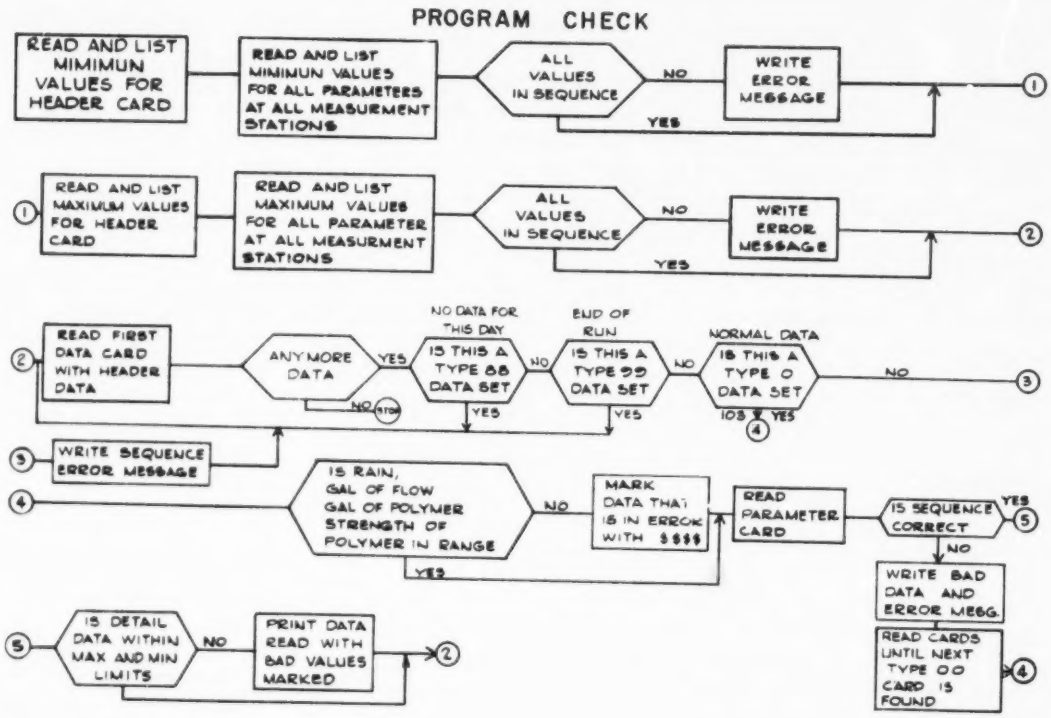
DATE

STATION	ABSORBANCE	FACTOR	MG/SAMPLE	DILUTION	RESULTS	COMPUTER
RAW						
PRIMARY EFFL						
FILTER EFFL						
FINAL EFFL						
RECIRC						
SLUDGE 1						
SLUDGE 2						
SLUDGE 3						
RAW SUP 1						
RAW SUP 2						
RAW SUP 3						
TREAT SUP						
BED DRAIN						
STANDARD						

425 mμ

FIGURE 1 - APPENDIX B. LABORATORY BENCH SHEET. (This is a reduced photograph of the 8½ x 11 inch sheet that went directly from analyst to computer cardpunch operator.)

The first program (Figure 2) consisted of an editing run involving such features as whether or not given data entries fitted within pre-selected maximum/minimum limits. Any values which exceeded these limits were printed out for further review to determine whether they had been properly derived and transcribed. The editing program included the ability to seek and identify other anomalies and recorded data typical of most programs in which data processing is undertaken.


PROGRAM CHECK
READ AND LIST MIMIMUN VALUES FOR HEADER CARD
READ AND LIST MINIMUN VALUES FOR ALL PARAMETERS AT ALL MEASUREMENT STATIONS
ALL VALUES IN SEQUENCE
NO
YES
WRITE ERROR MESSAGE
READ AND LIST MAXIMUM VALUES FOR HEADER CARD
READ AND LIST MAXIMUM VALUES FOR ALL PARAMETER AT ALL MEASUREMENT STATIONS
READ FIRST DATA CARD WITH HEADER DATA
ANY MORE DATA
NO DATA FOR THIS DAY
IS THIS A TYPE 88 DATA SET
END OF RUN
IS THIS A TYPE 99 DATA SET
NORMAL DATA
IS THIS A TYPE 0 DATA SET
WRITE SEQUENCE ERROR MESSAGE
IS RAIN, GAL OF FLOW GAL OF POLYMER STRENGTH OF POLYMER IN RANGE
MARK DATA THAT IS IN ERROR WITH $$$$
READ PARAMETER CARD
IS SEQUENCE CORRECT
WRITE BAD DATA AND ERROR MESG.
READ CARDS UNTIL NEXT TYPE 00 CARD IS FOUND
IS DETAIL DATA WITHIN MAX AND MIN LIMITS
PRINT DATA READ WITH BAD VALUES MARKED

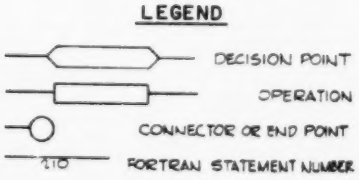


FIGURE 2 - APPENDIX B. FLOW DIAGRAM OF EDITING PROGRAM. (Unproofed daily data, cardpunched directly from analysts' bench sheets, was reviewed by this general program before further processing.)

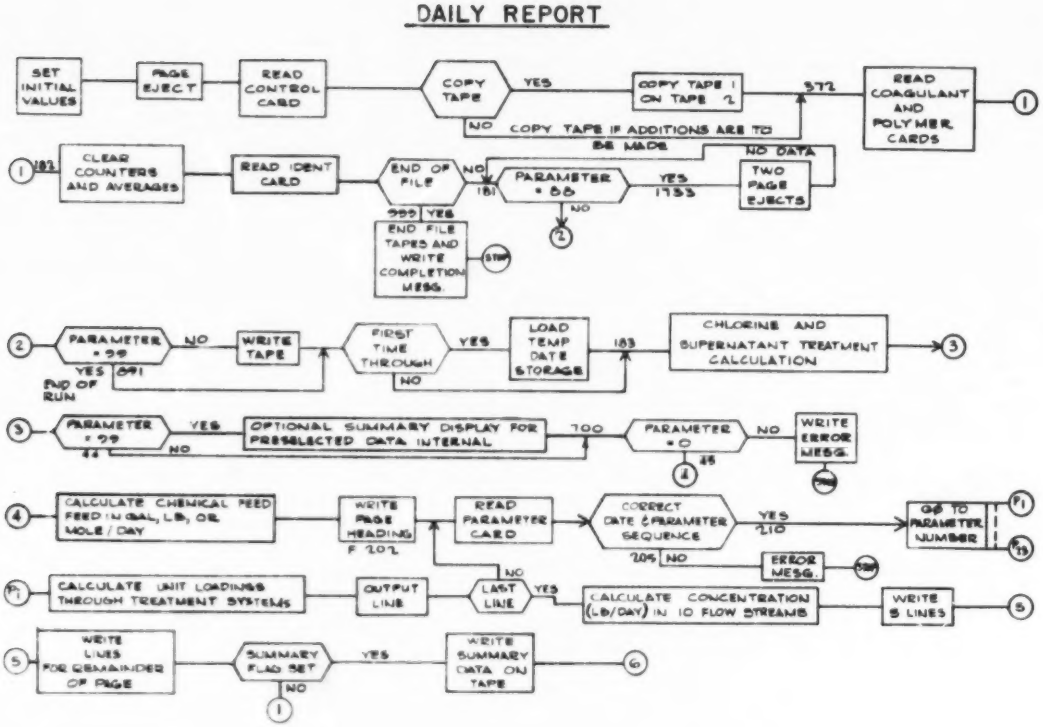
Another data processing program was called the Daily Report Program (Figure 3). This program took edited and reconciled data and organized it into a condensed matrix along with extended calculations. The printout, for a given day, fit onto a conventional 11 x 14 inch computer printout sheet. This single sheet showed every item of data recorded for a particular day in the condensed data matrix. This section of the daily printout constituted a "card image" of the raw input from the daily bench sheets. In addition to the card image section, daily reports also had results of over 100 calculations based on the data processed on that particular day.

Loadings in pounds per day at any of 12 sample stations were computed for suspended solids, suspended volatile solids, BOD_5, COD, and phosphorus. Ratios were computed for BOD_5/COD and volatile solids fractions at these same sample stations. Both primary and overall percentage removals were computed for suspended solids, BOD_5, phosphorus, total Kjeldahl nitrogen, and settleable solids. Hydraulic and solids loadings were calculated for both primary and final clarifiers, with and without recirculation. Trickling filter hydraulic and organic loadings were calculated in several different ways, as were loadings to the anaerobic digesters.

The amount of metal salt and polymers being added including mole ratios, pounds per day, and milligrams per liter were calculated and recorded. Cost of chemicals used were computed in cents per thousand gallons. All of these numbers were included on the single computer printout sheet for each day.

Selected series of Daily Reports could be fed into the final program, the Statistical Report (Figure 4). Unlike Daily Reports, a Statistical Report was relatively long. It covered 36 conventional computer output pages. On a given page, for example, a parameter such as incoming BOD_5 concentration would be analyzed and displayed. The Statistical Program computed and reported the following: the number of occurrences being analyzed, maximum and minimum values, arithmetic mean, standard deviation, standard deviation divided by the mean, and the mean plus or minus one and two standard deviations. In addition to the above tabulation, the page showed tabulated class interval printouts for five selected sample stations in the plant. The limitation to five stations was dictated by space limitations on the printout paper. These class interval tabulations were cumulative probability tables which showed the group limits of the class intervals and the plotting position of each, the population within each group, exceedence values within groups (95% Gaussian normality), and cumulative frequency. These tables could be used by an experienced observer as a histogram. Also, technicians could take data from these tables and plot probability graphs very rapidly to examine normality of distribution.

The data processing system as described to this point was pursued for a period of many months. At this point, even the highly condensed formats had generated an enormous amount of computer output paper. It became a



LEGEND

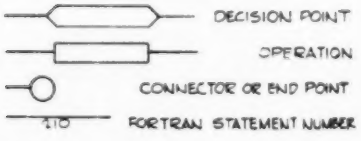
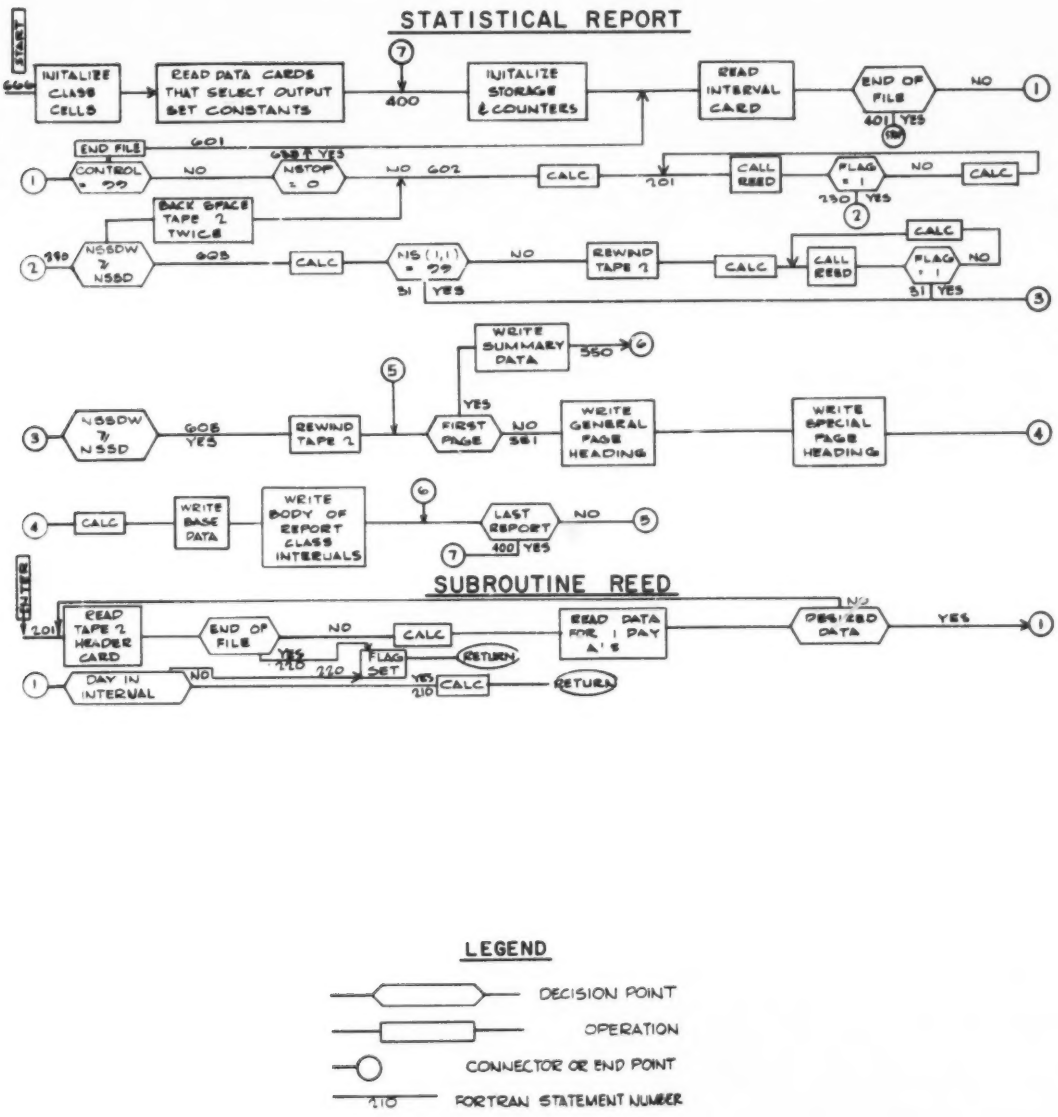


FIGURE 3 - APPENDIX B. PROGRAMING SEQUENCE USED TO PRODUCE DAILY REPORTS. (In addition to a card image of all pertinent data, printout included condensed results of over a hundred extended calculations.)



LEGEND

DECISION POINT

OPERATION

CONNECTOR OR END POINT

210 FORTRAN STATEMENT NUMBER

FIGURE 4 - APPENDIX B. TERMINAL PROGRAM DEVELOPED FOR STATISTICAL STUDIES. (This flow diagram outlines an extended and rigorous program of numerical analysis; towards end of the project, statistical results were transformed into computer generated plots.)

real burden, for example, to compare a statistical program output for several different operating runs. The next step was to convert all of the paper output into microfiche.

A basic microfiche format was developed as follows: using a 14 x 16 space card, daily reports were arranged to place the seven days of one week in the vertical fourteen-space column. This left blank spaces between each day and these spaces were available for summary runs which accumulated and reported back arithmetic means for any period of time selected by the operator. With a week's data so arranged in a vertical format, the balance of the microfiche card would accommodate fifteen more weeks, giving essentially three months of data per microfiche card. Once the observer became accustomed to this particular format, he could compare a very large number of cards in a short time. This particular style also let him scan Mondays or Saturdays, for instance, in a very direct manner.

Conversion of Statistical Reports to microfiche formats required a slightly different approach. As mentioned earlier, 36 computer sheets were required to provide a Statistical Report for a given period of time. Using 12 of the 14 available vertical positions on a fiche, a Statistical Report could be completed in a vertical line three microfiche long. As many as 16 Statistical Reports could be placed side by side. If the selection of periods for Statistical Reports was properly made, a rapid and very instructive survey of specific items could be made. For example, if the observer wanted to compare effluent phosphorus concentrations (mg/l) for various periods of time when different plant operations were being performed, all he would have to do is go vertically to the proper position and then read horizontally across all of the operating periods involved.

Some of the data generated in a project of this type will not fit the classic aritnmetic patterns of distribution and normality. This is particularly true where active zero end constraint is involved, such as observations of dissolved oxygen in treated effluent. Project personnel quickly learned to judge whether or not microfiche data was geometrically normal. However, these assumptions could not be presented without more rigorous testing of the data. To do this, data which appeared to be geometrically normal was plotted on log probability paper. If a straight line was obtained by this manipulation, the geometric mean was selected and reported as the proper "average" for this family of data. If a family of data exhibited a Gaussian distribution, plotting the data on arithmetic probability paper allowed verification and selection of an "average". Sometimes data were irregular in terms of either of these classic distributions, and in those cases all characteristics were studied and finally the best approximation of an "average" was extracted and reported.

Late in the project, computer probability plots and scatter diagrams were generated to speed up the process of displaying analyzed data.

Some of these plots are shown in the body of this report. Except for the speed and convenience of computer plotting, these were not essential to the project. On the other hand, the basic collection and manipulation of data by electronic computers were absolutely mandatory to successful analysis of this investigation.

APPENDIX C

DETAILED DATA SUMMARY FOR EXTENDED ALUM RUN

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

APRIL 1971

DATE	RW FLOW* (MGD)	BOD_5 (mg/1)			COD (mg/1)			SS (mg/1)			TP (mg/1 P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.46	-	-	-	384	232	100	136	66	25	12.7	9.3	6.0	0
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	1.54	-	-	-	384	152	70	58	70	17	13.8	12.8	10.9	0
5	1.45	188	98	16	364	152	60	284	92	5	14.6	12.8	8.2	0
6	1.46	174	86	19	452	265	130	244	82	14	15.1	13.3	9.9	0
7	1.22	154	-	-	532	-	216	182	-	28	13.9	-	11.8	0
8	1.39	162	74	12	532	-	126	268	98	18	14.8	14.0	11.8	0
9	1.36	-	-	-	-	-	-	-	-	-	-	-	-	0
10	1.56	-	-	-	-	-	-	-	-	-	-	-	-	0
11	1.17	-	-	-	348	238	118	186	62	13	14.3	14.1	12.5	0
12	1.66	124	-	10	428	274	107	268	142	23	18.2	17.2	7.8	0
13	1.22	109	48	8	484	224	99	178	118	24	17.4	8.6	5.6	0
14	1.41	132	60	10	516	281	142	368	74	16	13.8	12.4	9.0	0
15	1.48	-	-	-	448	272	111	248	98	17	14.8	14.8	10.2	0
16	1.40	-	-	-	-	-	-	-	-	-	-	-	-	0
17	2.13	-	-	-	-	-	-	-	-	-	-	-	-	0
18	1.26	-	-	-	329	219	92	186	56	6	10.2	9.9	7.3	0
19	1.85	79	58	10	324	234	51	160	94	13	12.3	10.3	3.6	2.98
20	1.85	79	45	8	293	194	43	118	88	7	9.7	6.7	0.4	4.72
21	1.44	128	106	11	356	282	48	156	88	11	12.1	6.8	0.3	2.76
22	1.48	-	-	-	416	194	37	133	36	3	13.2	6.0	0.3	1.97
23	1.43	-	-	-	-	-	-	-	-	-	-	-	-	-
24	1.46	-	-	-	-	-	-	-	-	-	-	-	-	-
25	1.45	172	98	-	397	222	75	218	88	18	10.1	7.5	1.4	.44
26	1.59	146	69	12	483	286	24	152	76	7	12.8	10.7	1.1	1.91
27	1.49	171	73	8	376	234	40	194	188	5	13.6	8.2	0.3	1.88
28	1.47	172	82	4	424	229	36	182	82	4	11.8	7.5	0.3	2.18
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg.	1.49	142	74	11	409	232	86	196	89	14	13.5	10.6	5.9	2.36

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

MAY 1971

DATE	RW FLOW* (MGD)	BOD_5 (mg/1)			COD (mg/1)			SS (mg/1)			TP (mg/1 P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1														
2	1.37	-	-	-	329	255	51	112	92	7	11.5	10.5	0.9	1.97
3	1.48	185	126	12	458	318	20	142	144	4	15.4	12.9	0.5	1.44
4	1.27	152	89	7	376	283	39	168	100	8	13.2	10.6	0.7	1.85
5	1.36	230	115	13	528	266	20	228	120	10	10.1	10.4	0.5	2.26
6	1.40	155	88	9	364	245	43	244	146	10	10.2	7.9	-	2.17
7	1.34	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1.26	181	140	16	376	258	67	166	76	9	11.2	10.0	1.3	2.03
10	1.38	-	-	-	388	249	31	284	112	10	14.5	10.2	1.5	1.43
11	1.33	-	-	-	388	237	44	148	86	12	13.9	11.2	0.8	1.56
12	1.30	-	-	-	520	250	31	374	72	4	9.2	7.6	1.0	2.40
13	1.30	-	-	-	426	210	39	238	82	5	13.6	6.2	0.9	1.62
14	1.26	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	1.29	-	-	-	312	200	20	108	88	6	12.1	7.2	0.3	2.35
17	1.37	-	-	-	432	320	35	164	182	15	14.2	-	0.7	1.59
18	1.35	-	-	-	516	252	60	164	84	4	14.7	9.6	0.3	1.56
19	1.34	-	-	-	446	314	23	282	112	3	12.4	9.5	0.4	1.86
20	1.32	-	-	-	349	256	39	110	106	12	8.2	8.8	0.5	2.86
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	1.33	142	116	8	372	301	32	134	100	11	-	-	-	-
24	1.39	240	132	14	466	278	24	312	176	11	12.2	10.5	0.5	1.83
25	1.31	175	106	10	447	257	44	252	106	9	11.9	9.2	0.7	1.99
26	1.71	188	122	8	482	262	39	234	98	6	16.1	9.9	0.8	1.13
27	1.49	120	84	10	269	211	31	144	78	5	9.8	8.3	0.8	2.12
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	1.56	183	134	34	375	298	51	138	170	18	10.5	12.4	0.9	1.89
Avg.	1.37	177	114	13	410	258	37	197	111	8	12.2	9.6	0.7	1.90

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

JUNE 1971

DATE	RW FLOW* (MGD)	BOD_5 (mg/l)			COD (mg/l)			SS (mg/l)			TP (mg/l P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.52	181	124	9	360	253	32	186	104	9	10.6	9.9	0.7	1.92
2	1.50	177	96	7	504	253	43	248	106	9	10.5	9.0	0.8	1.97
3	1.44	143	81	4	376	257	-	148	56	-	11.0	9.8	0.6	1.96
4	1.38	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	1.33	116	67	4	408	276	36	168	90	11	10.4	8.3	0.4	2.64
7	1.48	162	105	7	588	-	39	196	-	16	14.6	12.1	0.8	1.52
8	1.35	163	-	2	492	282	66	128	-	2	12.5	12.2	0.4	1.84
9	1.32	-	-	-	428	247	66	198	108	4	11.9	9.6	0.5	1.97
10	1.31	230	137	7	345	282	31	200	124	9	9.2	8.3	0.4	2.57
11	1.33	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	1.29	158	109	5	310	212	35	114	86	11	9.5	8.0	0.4	2.98
14	1.37	208	125	8	404	273	47	172	116	13	13.1	10.3	0.6	1.73
15	1.31	214	156	9	353	262	43	166	96	9	11.5	9.3	0.6	2.86
16	1.33	194	140	9	400	261	40	180	102	12	11.6	9.4	0.6	2.01
17	1.30	113	74	4	388	237	47	148	74	12	8.7	7.9	0.4	2.74
18	1.34	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	1.33	171	88	5	247	191	43	106	66	3	10.9	6.6	0.3	2.52
21	1.84	122	67	17	368	208	51	164	76	19	9.0	7.5	1.0	1.87
22	1.32	114	87	8	293	218	32	116	82	16	15.6	13.7	1.0	1.50
23	1.37	210	126	11	439	203	38	242	124	10	13.2	9.6	0.5	1.71
24	1.34	138	97	6	380	234	40	146	122	18	10.9	8.9	0.5	2.12
25	1.32	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	1.30	187	131	8	334	247	43	136	96	6	10.2	8.1	0.5	2.75
28	1.47	-	-	-	388	294	66	196	124	19	12.9	10.9	1.4	1.63
29	1.36	175	117	9	490	251	55	246	108	17	10.3	7.9	0.4	2.21
30	1.36	187	107	6	-	262	35	166	96	6	12.5	8.9	0.3	1.82
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg.	1.38	168	107	7	395	248	44	189	109	11	11.4	9.4	0.6	2.08

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE I - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

JULY 1971

DATE	RW FLOW* (MGD)	BOD_5 (mg/l)			COD (mg/l)			SS (mg/l)			TP (mg/l P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.40	235	119	5	340	-	44	132	-	7	12.0	-	0.6	1.84
2	1.33	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	1.30	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1.32	176	107	5	380	252	52	176	96	8	13.4		0.6	1.75
6	1.37	216	100	3	404	220	52	176	86	4	11.2	8.5	0.4	2.02
7	1.38	218	-	5	425	200	38	206	78	4	13.8	8.1	0.4	1.63
8	1.39	-	-	-	344	232	36	148	64	8	10.5	6.5	0.4	2.12
9	1.31	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	1.23	-	-	7	368	178	43	148	64	6	9.1	5.1	0.3	3.26
12	1.31	167	-	6	432	313	51	154	84	5	11.7	9.2	0.7	2.02
13	1.33	245	212	8	381	249	44	130	84	4	10.0	7.6	0.5	2.33
14	1.32	258	208	13	499	257	48	166	96	14	11.8	7.7	0.6	1.99
15	1.32	225	165	8	360	245	51	98	66	8	10.3	7.6	0.7	2.28
16	1.32	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	1.34	245	185	5	379	227	44	130	72	9	10.7	7.3	0.5	2.54
19	1.43	211	-	6	464	278	54	184	98	4	10.5	8.4	0.7	2.06
20	1.34	259	186	6	356	268	32	144	88	5	10.3	8.6	0.5	2.24
21	1.35	265	181	5	439	229	36	160	82	5	11.8	8.0	0.5	1.95
22	1.35	228	161	6	404	196	47	190	64	6	10.4	6.5	0.5	2.21
23	1.54	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	1.40	158	109	3	368	166	32	114	32	7	9.3	7.1	0.2	2.80
26	1.41	215	91	6	384	235	35	136	84	8	11.1	8.7	0.7	1.98
27	1.54	157	101	6	408	238	37	186	100	9	10.0	8.6	0.6	2.01
28	1.80	135	78	7	235	149	37	126	56	9	5.0	4.1	0.4	3.44
29	1.74	91	-	7	214	134	39	98	40	11	5.5	4.9	0.7	3.24
30	1.63	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg.	1.40	206	143	6	379	225	43	150	77	7	10.4	7.4	0.5	2.29

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE I - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

AUGUST 1971

DATE	RW FLOW* (MGD)	BOD_5 (mg/l)			COD (mg/l)			SS (mg/l)			TP (mg/l P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.46	133	76	2	283	190	28	126	74	7	9.1	8.7	0.0	2.74
2	1.56	153	92	3	313	219	51	174	90	11	9.7	7.6	0.6	2.05
3	1.55	173	-	5	332	225	40	-	-	-	9.2	8.0	0.8	2.17
4	1.50	150	126	8	376	235	35	146	94	13	10.0	8.1	0.8	2.07
5	1.34	125	90	3	282	220	35	144	98	9	10.4	6.6	0.6	2.22
6	1.35	-	-	-	-	-	-	-	-	-	-	-	-	-
7	1.27	-	-	-	-	-	-	-	-	-	-	-	-	-
8	1.52	137	106	3	348	244	35	102	104	7	9.5	7.6	0.6	2.54
9	1.33	310	117	13	445	334	58	146	128	11	12.0	10.6	1.1	1.94
10	1.38	160	92	5	470	255	35	158	112	13	11.0	7.7	0.7	2.04
11	1.43	217	121	7	400	258	50	188	100	10	11.4	9.1	0.6	1.90
12	1.38	75	97	4	390	333	46	332	108	7	11.5	8.2	0.6	1.95
13	1.46	-	-	-	-	-	-	-	-	-	-	-	-	-
14	1.92	-	-	-	-	-	-	-	-	-	-	-	-	-
15	1.74	113	73	4	263	202	49	84	66	5	9.3	8.0	0.7	2.25
16	1.62	168	113	11	411	250	49	128	70	14	11.6	10.2	1.1	1.65
17	1.70	150	110	8	316	234	53	126	82	6	10.2	8.6	1.0	1.79
18	1.58	190	96	9	536	260	41	196	98	9	12.0	9.6	0.7	1.63
19	1.58	142	90	11	328	230	60	116	96	15	10.2	8.0	1.1	1.92
20	1.63	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.56	-	-	-	-	-	-	-	-	-	-	-	-	-
22	1.50	183	119	3	512	250	48	128	76	10	11.5	9.6	0.6	2.11
23	1.51	177	141	6	384	267	43	162	126	20	10.6	8.5	0.9	1.94
24	1.51	315	151	1	543	281	76	184	98	14	8.5	7.9	0.9	2.41
25	1.64	130	97	2	372	290	55	134	110	13	9.4	8.3	0.8	2.01
26	1.44	152	121	6	309	270	47	186	102	15	11.9	-	1.3	1.81
27	1.32	-	-	-	-	-	-	-	-	-	-	-	-	-
28	1.52	-	-	-	-	-	-	-	-	-	-	-	-	-
29	1.43	190	120	3	370	255	39	182	90	11	10.8	9.8	0.8	2.36
30	1.52	328	185	6	392	264	58	132	114	10	12.4	10.0	1.1	1.64
31	1.48	240	156	7	388	280	45	210	104	8	12.2	7.9	0.9	1.72
Ave.	1.50	179	113	6	381	250	47	158	143	11	10.6	8.2	0.8	2.04

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

SEPTEMBER 1971

DATE	RW FLOW* (MGD)	BOD_5 (mg/l)			COD (mg/l)			SS (mg/l)			TP (mg/l P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.46	258	149	7	369	272	47	138	114	14	9.6	8.2	0.7	2.17
2	1.38	230	145	6	342	252	54	168	102	15	12.0	8.8	0.9	1.87
3	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-
4	1.60	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1.45	-	-	-	-	-	-	-	-	-	-	-	-	-
6	1.40	285	212	17	352	338	75	130	124	17	9.7	12.3	1.6	2.28
7	1.18	232	182	13	363	353	63	138	150	14	12.4	11.2	1.2	2.12
8	1.37	250	160	7	555	285	63	170	126	15	10.8	9.3	0.7	2.09
9	1.30	225	155	9	336	263	65	124	122	11	12.2	10.8	0.9	1.95
10	1.40	-	-	-	-	-	-	-	-	-	-	-	-	-
11	1.27	-	-	-	-	-	-	-	-	-	-	-	-	-
12	1.41	260	190	9	384	265	48	114	82	8	14.3	9.6	0.8	1.81
13	1.43	262	165	6	428	289	40	116	96	7	16.0	13.4	1.3	1.35
14	1.41	260	175	6	432	261	51	140	100	13	12.1	-	0.6	1.82
15	1.53	262	145	4	450	272	43	154	104	7	13.4	9.2	0.3	1.51
16	1.17	168	88	4	352	230	40	114	58	2	11.3	9.1	0.2	2.34
17	1.18	-	-	-	-	-	-	-	-	-	-	-	-	-
18	1.43	-	-	-	-	-	-	-	-	-	-	-	-	-
19	1.34	168	98	4	400	231	55	140	88	12	14.0	7.2	0.2	1.94
20	1.41	165	84	1	427	229	48	164	96	12	11.2	5.4	0.0	1.96
21	1.29	135	81	4	436	240	56	140	100	21	11.1	6.6	0.6	2.16
22	1.69	100	70	3	395	229	63	198	102	7	8.7	5.5	0.9	2.11
23	1.65	100	67	3	273	230	32	94	100	10	8.2	5.3	0.1	2.29
24	1.62	-	-	-	-	-	-	-	-	-	-	-	-	-
25	1.81	-	-	-	-	-	-	-	-	-	-	-	-	-
26	1.61	153	104	3	290	220	47	110	24	15	10.2	7.6	0.4	1.89
27	1.58	160	104	4	431	269	55	150	140	13	11.4	10.2	0.9	1.72
28	1.51	223	94	5	329	257	44	116	120	20	10.2	-	0.6	2.01
29	1.41	155	120	5	378	262	40	116	112	8	11.4	8.4	0.4	1.93
30	1.26	160	110	3	384	305	48	166	124	12	11.5	8.8	0.9	2.14
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg.	1.44	201	128	6	386	264	51	138	104	11	11.5	8.8	0.7	1.97

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

OCTOBER 1971

DATE	RW FLOW* (MGD)	BOD_5 (mg/l)			COD (mg/l)			SS (mg/l)			TP (mg/l P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-
2	1.49	-	-	-	-	-	-	-	-	-	-	-	-	-
3	1.57	145	74	4	204	146	38	204	84	10	3.7	5.4	0.1	6.28
4	1.78	75	60	4	173	135	35	78	50	9	5.5	5.7	0.4	3.16
5	1.76	146	61	4	221	167	47	56	76	13	6.7	6.5	0.5	2.63
6	1.85	80	60	4	332	206	42	110	110	12	7.6	6.5	0.5	1.88
7	1.78	155	80	1	364	209	34	186	120	8	9.3	7.8	0.7	1.60
8	1.63	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1.61	-	-	-	-	-	-	-	-	-	-	-	-	-
10	1.57	79	68	0	300	243	34	72	60	9	8.9	8.4	0.5	2.61
11	1.52	184	217	5	388	292	44	100	118	4	11.9	9.5	1.0	1.46
12	1.51	147	95	2	348	270	32	86	200	0	13.0	10.2	0.8	1.35
13	1.49	194	134	2	352	333	39	260	162	-	10.2	10.0	0.7	1.74
14	1.60	148	130	4	332	308	52	220	218	-	9.2	9.5	0.7	1.80
15	1.55	-	-	-	-	-	-	-	-	-	-	-	-	-
16	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-
17	1.56	182	160	3	376	268	43	252	200	-	12.0	9.0	0.7	1.95
18	1.76	120	96	4	374	248	58	160	124	20	10.0	-	1.1	1.50
19	1.25	80	50	-	86	125	43	188	260	28	2.4	3.8	0.5	8.81
20	2.44	75	60	5	101	-	39	52	50	2	3.2	4.0	0.5	3.39
21	1.74	62	40	3	112	104	43	212	110	6	3.5	3.9	0.8	4.34
22	1.75	-	-	-	-	-	-	-	-	-	-	-	-	-
23	1.72	-	-	-	-	-	-	-	-	-	-	-	-	-
24	1.72	93	83	4	476	153	35	178	154	25	7.7	7.6	1.2	2.75
25	2.10	96	63	5	223	173	46	154	134	37	9.2	7.6	1.6	1.37
26	1.85	89	54	4	548	158	38	204	74	16	12.4	5.8	0.4	1.29
27	1.95	102	58	3	270	174	36	218	208	77	8.4	6.6	0.3	2.06
28	1.85	85	64	3	272	155	31	96	84	19	6.1	6.2	0.4	2.34
29	1.88	-	-	-	-	-	-	-	-	-	-	-	-	-
30	1.84	-	-	-	-	-	-	-	-	-	-	-	-	-
31	1.78	130	66	4	248	200	31	170	98	35	9.6	9.6	0.9	2.13
Avg.	1.78	117	84	3	290	203	40	155	128	19	8.1	7.2	0.6	2.69

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

NOVEMBER 1971

DATE	RW FLOW* (MGD)	BOD_5 (mg/1)			COD (mg/1)			SS (mg/1)			TP (mg/1 P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.77	123	80	3	268	184	23	172	110	12	11.5	8.8	1.2	1.30
2	1.60	98	81	3	265	211	43	148	130	34	10.2	8.4	0.9	1.62
3	1.68	102	61	2	268	203	42	126	152	32	11.5	8.6	0.9	1.37
4	1.61	98	56	1	238	176	31	460	394	43	10.2	7.6	1.1	1.61
5	1.46	-	-	-	-	-	-	-	-	-	-	-	-	-
6	1.62	-	-	-	-	-	-	-	-	-	-	-	-	-
7	1.50	145	87	2	314	216	43	150	110	10	12.0	8.1	0.8	2.03
8	1.60	210	100	4	420	223	37	146	76	9	12.4	6.9	0.8	1.33
9	1.55	217	89	2	364	220	47	80	66	15	12.2	10.0	0.7	1.40
10	1.45	177	108	4	389	214	39	334	84	15	12.2	7.0	0.4	1.49
11	1.50	140	103	3	305	210	44	94	90	67	12.0	8.1	0.4	1.47
12	1.53	-	-	-	-	-	-	-	-	-	-	-	-	-
13	1.26	-	-	-	-	-	-	-	-	-	-	-	-	-
14	1.34	233	124	7	-	-	-	-	-	-	11.2	8.0	0.9	2.43
15	1.37	167	109	2	371	274	51	172	98	19	12.0	10.4	0.8	1.61
16	1.48	169	80	2	375	242	43	154	94	23	13.4	9.6	0.5	1.33
17	1.68	225	100	4	608	223	39	276	148	-	11.4	6.1	0.7	1.38
18	1.68	102	72	3	392	192	35	106	84	26	10.2	7.0	-	1.54
19	1.49	-	-	-	-	-	-	-	-	-	-	-	-	-
20	1.53	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.38	144	107	1	323	222	31	100	118	13	12.0	8.9	0.4	2.20
22	1.51	144	103	2	384	223	31	260	124	22	13.4	8.3	0.6	1.31
23	1.56	147	100	4	348	209	31	86	68	9	12.2	7.8	1.0	1.39
24	1.44	-	-	-	-	-	-	-	-	-	-	-	-	-
25	1.46	-	-	-	-	-	-	-	-	-	-	-	-	-
26	1.35	-	-	-	-	-	-	-	-	-	-	-	-	-
27	1.38	-	-	-	-	-	-	-	-	-	-	-	-	-
28	1.40	169	109	3	345	226	56	134	86	6	11.0	8.9	0.7	2.37
29	1.42	204	149	9	409	339	68	148	168	-	-	-	-	-
30	1.49	134	122	18	445	336	87	136	188	36	11.0	13.0	2.4	1.61
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg.	1.50	157	97	4	360	255	44	172	125	23	11.7	8.5	0.8	1.62

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

DECEMBER 1971

DATE	RW FLOW* (MGD)	BOD_5 (mg/1)			COD (mg/1)			SS (mg/1)			TP (mg/1 P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.28	106	-	11	353	-	197	180	-	32	11.8	-	2.0	1.75
2	2.72	49	-	5	201	-	53	80	-	39	5.1	-	1.5	1.91
3	2.64	-	-	-	-	-	-	-	-	-	-	-	-	-
4	2.60	-	-	-	-	-	-	-	-	-	-	-	-	-
5	3.51	54		20	253	-	29	110	-	32	4.1	-	1.2	2.45
6	3.20	48	-	6	134	-	46	154	-	-	4.2	-	1.8	1.97
7	2.99	46	-	5	165	-	44	42	-	35	4.2	-	2.1	2.11
8	2.79	32	-	2	224	-	36	84	-	28	2.7	-	1.5	3.51
9	3.17	27	-	8	-	-	40	-	-	-	2.6	-	1.6	3.21
10	3.38	-	-	-	-	-	-	-	-	-	-	-	-	-
11	3.75	-	-	-	-	-	-	-	-	-	-	-	-	-
12	3.57	44	-	-	91	-	51	38	-	31	4.2	-	-	2.36
13	3.57	39	-	-	92	-	48	78	-	34	5.1	-	2.4	1.54
14	3.27	30	-	13	129	-	43	46	-	16	4.2	-	1.8	1.93
15	3.14	52	-	18	103	-	35	70	-	20	-	-	-	-
16	2.88	55	-	5	86	-	35	48	-	22	6.7	-	2.2	1.37
17	2.68	-	-	-	-	-	-	-	-	-	-	-	-	-
18	2.70	-	-	-	-	-	-	-	-	-	-	-	-	-
19	2.45	57	-	5	115	-	20	28	-	6	5.7	-	0.9	1.89
20	2.50	194	-	4	216	-	-	-	-	-	6.5	-	1.5	1.63
21	2.36	63	-	3	178	-	36	-	-	-	7.6	-	0.8	1.47
22	2.28	-	-	-	-	-	-	-	-	-	-	-	-	-
23	2.28	-	-	-	-	-	-	-	-	-	-	-	-	-
24	2.23	-	-	-	-	-	-	-	-	-	-	-	-	-
25	1.92	-	-	-	-	-	-	-	-	-	-	-	-	-
26	1.80	-	-	-	-	-	-	-	-	-	-	-	-	-
27	2.00	-	-	-	-	-	-	-	-	-	-	-	-	-
28	1.89	-	-	-	-	-	-	-	-	-	-	-	-	-
29	1.89	-	-	-	-	-	-	-	-	-	-	-	-	-
30	1.85	-	-	-	-	-	-	-	-	-	-	-	-	-
31	1.95	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg.	2.61	60	-	8	167	-	51	80	-	27	5.3	-	1.6	2.08

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

JANUARY 1972

DATE	RW FLOW* (MGD)	BOD_5 (mg/l)			COD (mg/l)			SS (mg/l)			TP (mg/l P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.80	-	-	-	-	-	-	-	-	-	-	-	-	-
2	1.85	113	80	2	221	159	58	632	602	468	12.0	11.0	-	1.64
3	1.99	127	104	-	416	330	39	138	92	22	9.0	9.6	2.4	1.48
4	1.85	85	-	2	206	164	31	98	66	13	6.4	5.8	1.4	2.23
5	1.90	145	72	3	214	167	38	102	68	13	6.4	6.5	1.2	2.17
6	1.98	98	63	-	270	182	48	108	44	14	6.8	5.3	1.2	1.96
7	1.99	-	-	-	-	-	-	-	-	-	-	-	-	-
8	2.11	-	-	-	-	-	-	-	-	-	-	-	-	-
9	2.02	132	99	5	250	177	31	144	110	-	8.9	7.3	1.1	2.03
10	1.87	86	74	5	322	204	35	112	116	14	9.7	7.8	1.5	1.46
11	1.91	75	53	2	228	186	38	78	82	13	8.8	7.8	1.4	1.57
12	1.83	107	67	4	206	176	34	118	52	6	7.7	6.3	1.1	1.88
13	1.72	109	63	4	234	182	36	100	62	8	7.6	6.1	0.8	2.02
14	1.63	-	-	-	-	-	-	-	-	-	-	-	-	-
15	1.69	-	-	-	-	-	-	-	-	-	-	-	-	-
16	1.67	91	90	2	288	192	40	84	80	12	8.8	6.7	0.7	2.48
17	1.84	129	-	2	352	-	68	108	-	32	10.8	8.4	1.2	1.33
18	1.70	189	90	4	328	218	39	194	112	9	8.8	7.9	1.0	2.07
19	1.75	125	86	4	276	206	47	102	78	11	9.4	7.2	1.0	1.88
20	1.65	114	64	2	250	166	28	212	60	-	10.1	5.1	0.6	1.96
21	1.75	-	-	-	-	-	-	-	-	-	-	-	-	-
22	1.17	-	-	-	-	-	-	-	-	-	-	-	-	-
23	1.77	164	97	1	326	211	35	120	92	10	11.0	7.9	0.5	1.87
24	1.83	174	87	2	376	219	47	132	106	13	12.8	8.7	0.9	1.32
25	1.73	159	99	-	402	236	39	146	88	7	10.0	7.0	0.5	1.79
26	1.73	200	108	2	434	179	43	460	78	8	9.6	5.2	0.5	1.87
27	1.78	190	133	3	321	188	39	122	60	1	8.9	6.4	0.6	1.96
28	1.75	-	-	-	-	-	-	-	-	-	-	-	-	-
29	1.17	-	-	-	-	-	-	-	-	-	-	-	-	-
30	1.74	152	102	4	302	226	27	136	98	-	11.5	7.8	0.5	1.82
31	1.71	161	99	3	387	229	40	154	96	2	10.8	7.6	0.6	1.68
Avg.	1.77	133	82	3	300	200	40	164	107	36	9.4	7.2	1.0	1.84

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

FEBRUARY 1972

DATE	RW FLOW* (MGD)	BOD_5 (mg/1)			COD (mg/1)			SS (mg/1)			TP (mg/1 P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	2.01	141	68	6	334	194	59	120	96	36	9.6	6.1	2.0	1.61
2	1.82	143	88	2	370	233	44	172	114	20	10.8	7.7	0.8	1.58
3	1.61	140	55	3	269	178	48	114	68	8	8.6	6.3	0.4	2.24
4	1.51	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1.71	-	-	-	-	-	-	-	-	-	-	-	-	-
6	1.72	166	103	5	302	190	24	114	90	7	12.7	7.6	0.2	1.67
7	1.78	167	85	6	414	240	56	254	100	14	12.2	9.4	0.4	1.43
8	1.69	210	98	5	372	212	36	150	94	8	10.5	7.3	0.3	1.75
9	1.73	163	112	1	440	255	44	140	102	7	10.5	6.7	0.4	1.71
10	1.62	126	78	2	332	238	52	90	108	6	10.7	7.0	0.4	1.91
11	1.77	-	-	-	-	-	-	-	-	-	-	-	-	-
12	1.74	-	-	-	-	-	-	-	-	-	-	-	-	-
13	1.73	156	117	2	312	312	40	104	114	7	8.4	7.9	0.4	2.51
14	1.75	177	104	1	440	255	33	142	122	11	12.8	8.4	0.5	1.38
15	1.73	152	92	2	-	-	-	96	104	7	11.6	7.3	0.4	1.54
16	1.71	185	130	3	392	250	31	136	106	10	12.8	8.2	0.4	1.42
17	1.74	151	121	1	298	214	24	94	126	14	-	7.8	0.4	-
18	1.63	-	-	-	-	-	-	-	-	-	-	-	-	-
19	1.64	-	-	-	-	-	-	-	-	-	-	-	-	-
20	1.61	158	119	4	362	280	25	188	150	37	11.5	10.0	0.2	1.97
21	1.60	149	108	6	546	283	40	156	118	6	12.0	9.8	0.4	1.61
22	1.72	164	143	5	345	306	40	144	128	12	12.2	10.2	0.5	1.48
23	1.75	147	62	4	389	230	36	220	138	7	12.8	8.8	0.5	1.38
24	1.74	127	97	10	303	260	36	198	184	51	10.8	9.0	0.5	1.65
25	1.70	-	-	-	-	-	-	-	-	-	-	-	-	-
26	1.71	-	-	-	-	-	-	-	-	-	-	-	-	-
27	1.59	175	153	7	576	278	39	108	120	13	12.1	10.3	0.7	1.90
28	1.70	199	143	6	460	310	40	118	132	14	12.0	10.1	0.7	1.70
29	1.45	186	154	5	-	-	-	164	118	8	12.7	7.9	0.5	1.68
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg.	1.70	161	106	4	382	248	39	144	116	14	11.4	8.3	0.5	1.71

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 1 - APPENDIX C

DETAILED SUMMARY OF MAJOR PARAMETERS DURING EXTENDED ALUM RUN

MARCH 1972

DATE	RW FLOW* (MGD)	BOD_5 (mg/l)			COD (mg/l)			SS (mg/l)			TP (mg/l P)			MOLE RATIO (Al/P**)
		RW	PE	FE	RW	PE	FE	RW	PE	FE	RW	PE	FE	
1	1.65	250	181	5	508	340	51	190	162	7	10.8	9.2	0.4	1.74
2	1.54	147	114	6	320	273	43	102	106	7	12.2	8.1	0.3	1.68
3	1.63	-	-	-	-	-	-	-	-	-	-	-	-	-
4	1.68	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1.71	164	138	7	336	332	47	216	166	17	12.5	10.6	0.4	1.71
6	1.63	248	244	6	591	360	47	216	176	4	13.4	11.0	0.5	1.42
7	1.54	265	-	8	411	286	58	164	-	5	13.4	9.0	0.4	1.50
8	1.65	-	-	-	340	265	42	280	222	6	13.4	10.8	0.5	1.40
9	1.59	290	-	-	431	270	49	214	104	12	10.0	7.0	0.4	1 96
10	1.52	-	-	-	-	-	-	-	-	-	-	-	-	-
11	1.46	-	-	-	-	-	-	-	-	-	-	-	-	-
12	1.55	-	-	-	412	274	41	146	98	7	12.5	-	0.3	1.88
13	1.53	275	-	-	432	314	46	140	130	8	11.8	9.4	0.3	1.73
14	1.49	224	175	-	392	314	49	176	116	4	12.6	10.1	0.4	1.65
15	1.55	218	171	-	440	368	54	156	148	12	11.6	8.9	0.4	1.72
16	1.46	162	132	-	338	326	43	90	138	7	11.3	8.1	0.4	1.88
17	1.37	-	-	-	-	-	-	-	-	-	-	-	-	-
18	1.49	-	-	-	-	-	-	-	-	-	-	-	-	-
19	1.57	190	160	3	382	361	40	128	164	13	13.0	11.0	0.4	1.78
20	1.50	215	140	4	370	378	52	128	182	16	13.8	12.8	0.5	1 51
21	1.55	180	110	3	384	245	47	162	158	18	13.8	13.8	0.6	1.45
22	1.49	190	90	4	396	317	47	122	132	6	13.4	10.0	0.4	1.50
23	1.52	293	265	3	340	313	59	84	118	4	12.2	10.0	0.5	1.68
24	1.58	-	-	-	-	-	-	-	-	-	-	-	-	-
25	1.50	-	-	-	-	-	-	-	-	-	-	-	-	-
26	1.39	143	60	8	286	208	22	118	206	15	8.7	6.8	0.1	2 90
27	1.54	183	125	8	310	-	35	118	184	4	12.0	6.7	0.2	1.65
28	1.40	158	119	-	286	248	31	84	102	5	8.9	5.3	0.2	2.50
29	1.35	201	138	5	368	257	40	164	110	10	10.6	6.1	0.2	1.76
30	1.31	180	115	2	294	227	20	106	102	17	10.7	5.7	0.2	1.62
31	1.26	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg.	1.52	209	146	5	380	299	44	150	144	9	11.9	9.1	0.4	1 76

RW - Raw Wastewater
PE - Primary Effluent
FE - Final Effluent

SS - Suspended Solids
TP - Total Phosphorus
Flow*-Design = 1.5 MGD
P**- Tot. Phos. in RW

TABLE 2 - APPENDIX C

MONTHLY AVERAGE VALUES OF ADDITIONAL CHEMICAL PARAMETERS DURING EXTENDED ALUM RUN

MONTH	TOT. Al^{+++} (mg/l)		SO_4 (mg/l)		TOT. ALK. (mg/l as $CaCO_3$)		TURBIDITY (JTU)		TKN (mg/l)		NH_3-N* (mg/l)		NO_3-N* (mg/l)
	RW	FE	RW	FE	RW	FE	RW	FE	RW	FE	RW	FE	FE
APRIL 1971	1.0	1.1	59	97	195	110	165	27	24	13	20	13	2
MAY 1971	.5	1.8	81	169	193	62	162	9	27	13	20	12	3
JUNE 1971	.4	1.4	85	162	178	58	150	9	21	9	20	10	3
JULY 1971	.5	1.6	93	164	197	54	145	6	22	10	18	11	2
AUG. 1971	.4	1.4	109	183	208	71	141	7	24	10	18	10	3
SEPT. 1971	.3	2.1	121	212	192	44	72	8	26	11	20	10	3
OCT. 1971	.5	2.6	119	196	216	90	56	9	17	7	12	6	4
NOV. 1971	.4	1.7	102	189	226	67	62	11	25	12	18	10	3
DEC. 1971	.6	1.4	135	154	236	178	33	16	12	6	7	5	2
JAN. 1972	.2	2.2	122	182	242	117	53	9	22	11	16	10	2
FEB. 1972	.3	2.1	118	209	224	78	67	7	27	13	20	14	1
MARCH 1972	.3	1.8	118	221	228	67	73	7	27	13	20	13	1

RW - Raw Wastewater
FE - Final Effluent
N* - mg/l as N

TABLE 3 - APPENDIX C

MONTHLY AVERAGE VALUES OF PLANT OPERATING PARAMETERS

DURING EXTENDED ALUM RUN

MONTH	RECYCLE FLOW* (MGD)	pH		D.O. (mg/l)		WATER TEMP. (°F)		Cl_2 FEED** (LB/DAY)	TOT. Cl_2 RESIDUAL (mg/l)	FECAL COLIFORMS (No./ml)	
		RW	FE	RW	FE	RW	FE		FE	RW	FE
APRIL 1971	.46	7.1	7.0	1.2	6.6	73	70	0	0.0	30t	0
MAY 1971	2.1	7.3	7.0	.5	6.7	76	74	0	0.0	99t	770
JUNE 1971	.06	7.3	7.0	.2	6.2	81	84	0	0.0	113t	925
JULY 1971	.06	7.2	7.0	.1	6.6	84	82	100	1.1	116t	0
AUG. 1971	.06	7.4	6.9	.1	6.3	84	83	100	.9	306t	0
SEPT. 1971	.71	7.2	6.5	.1	6.5	83	81	110	1.5	108t	0
OCT. 1971	.57	7.2	6.6	.3	6.9	78	74	98	1.7	18t	0
NOV. 1971	.85	7.4	7.0	.3	7.4	74	69	95	1.6	93t	0
DEC. 1971	.45	7.3	7.2	.9	7.7	63	60	100	1.4	35t	0
JAN. 1972	.86	7.3	6.9	.5	7.6	61	57	100	1.6	80t	0
FEB. 1972	.82	7.3	6.7	.3	7.7	65	62	97	1.2	85t	0
MARCH 1972	.73	7.2	6.7	.4	6.7	67	66	100	1.3	62t	0

RW - Raw Wastewater
FE - Final Effluent
* - Settled sludge recirculation flow from final clarifier hopper to raw wastewater wet well.
** - Chlorine fed to trickling filter effluent just prior to entering final clarifier.

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